SCORESBY'S
MAGNETICAL
INVESTIGATIONS

PART II.

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MAGNETICAL

INVESTIGATIONS.

PART II.

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MAGNETICAL

INVESTIGATIONS.

BY THE

REV. WILLIAM SCORESBY, D.D.

FELLOW OF THE ROYAL SOCIETIES OF LONDON AND EDINBURGH;
CORRESPONDING MEMBER OF THE INSTITUTE OF FRANCE,
ETC. ETC.

PART II.

COMPRISING INVESTIGATIONS CONCERNING THE LAWS OR
PRINCIPLES AFFECTING THE POWER OF MAGNETIC STEEL PLATES
OR BARS IN COMBINATION, AS WELL AS SINGLY,
UNDER VARIOUS CONDITIONS AS TO MASS, HARDNESS, QUALITY,
FORM, ETC., AS ALSO CONCERNING THE COMPARATIVE
POWERS OF CAST IRON.

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TO THE

SECOND PART

OF THE

MAGNETICAL INVESTIGATIONS.

The experiments described in this second Part of "Magnetical Investigations," were, to a very considerable extent, made some years ago. They have been carried forward, however, at intervals, as the Author's arduous professional duties would admit, to the present time; and the publication of the results obtained has been deferred until all the objects of inquiry, belonging to the department of experimental research, which were originally contemplated, or have been suggested in the progress of the Investigations, have been completed.

It is hardly needful to say that the researches have been of a very elaborate nature and extent. The Tables given in this part of the work alone are the result of above four thousand observations on the deviations produced by the numerous magnetical plates and bars subjected to experiment,—each observation requiring the needle of a five-inch compass, after being disturbed by the influence of the magnet to be tested, to attain a stationary position, and the angle of deviation from the magnetical meridian, to be read off to within a minute or two of a degree. And besides this labour by the method of deviations, a large number of magnetical bars of the horse-shoe form, etc., had to be otherwise tested ; and the results obtained by the different modes of experiment required to be tabulated, in many cases at a considerable addition of trouble, for reducing the observations, and for obtaining the exact measures and weights of the bars or plates employed.

Similar investigations, as some of these here described, have, as is well known, been before made, and analogous results, in certain cases, obtained. The very extensive range of inquiry here pursued, however, with a constant adherence to the same modes of experimenting and testing, will, the Author hopes, not only excuse his having gone over some ground previously examined ; but will yield a measure of newness —by the unity of method and ampleness of investigation in the vast varieties of mass, form, quality, temper, and denomination of the magnets made use of—to the researches themselves.

Besides the experimental inquiries of the first and second Parts of these Magnetical Investigations, the Author has always contemplated, if leisure and health should, in Providence, be yielded him, to extend the work to two or three additional parts, embracing,—Practical Magnetics, with the application of these Investigations to the improvement of Magnetical Instruments and Apparatus; various original illustrations of, and experiments on, Magnetical Principles, and Phenomena, etc., etc.

It may be proper to state, however, that the two Parts of the work now before the public have been so adjusted as to be complete in themselves,—the last sheet of Part I., having been cancelled, and the substituted sheet G placed at the conclusion of this Part, in order that the connection betwixt the two portions might be more perfect.

The Author has only, in conclusion, to add, that whatever benefit to science his labours might be calculated to yield, or to his country,—for aiding the improvement of an instrument heretofore so exceedingly defective and uncertain as the sea-compass,—such benefit he is most desirous should be fully realized, and he has taken some pains to render that desire effective. In order to this, the Author has communicated, without reserve, to Messrs. Stubs (of the firm

"Peter Stubs"), manufacturers in steel, of Warrington,—the principal practical modes of constructing, magnetizing and testing the various kinds of plates and bars described in this work, or designed for being employed in magnetical apparatus. The employment by Messrs. Stubs of first-rate workmen in all the departments requisite for the construction of magnetical instruments, and especially for hardening or tempering; their extensive engagement as manufacturers of steel; with the deserved celebrity which their files and tools have gained for their firm, not only in England, but in many parts of the world abroad,—will at once enable them to undertake the kind of work referred to with peculiar advantages, and be a guarantee to the Author and to the Public, of its being faithfully and efficiently done.

Bradford, Yorkshire,
November 7th, 1843.

CONTENTS.

PART II.

INVESTIGATIONS CONCERNING THE LAWS OR PRINCIPLES AFFECTING THE POWER OF MAGNETIC STEEL PLATES OR BARS IN COMBINATION.

CHAPTER I.

PAGE
AS TO THE POWERS OF COMBINATIONS OF MAGNETIZED PLATES OF TEMPERED STEEL IN CONTACT - - 97
RESULTS - - - - - - - - 109

CHAPTER II.

ON THE POWERS OF COMBINATIONS OF MAGNETIZED STEEL PLATES, SEPARATED BY LIMITED SPACES - 119
RESULTS - - - - - - - - 128

CHAPTER III.

ON THE RELATIVE POWERS OF COMBINATIONS OF MAGNETIZED STEEL PLATES OR BARS, AS AFFECTED BY DIFFERENCES IN THE DEGREE OF HARDNESS OR NATURE OF THE TEMPER - - - - 132

PAGE

Sect. I.—Of the relative Powers of Combinations of Magnetized Steel Plates, as affected by changes in the TEMPER of the SAME SERIES of Plates - - . - - - - - 133

Sect. II.—Of the Magnetical Powers, separately, and in combination, of Steel Plates variously tempered, both in extent of surface, and in degree of hardness - - - - - 153

Sect. III.—Of the Magnetic Powers of Combinations of *very hard* Plates and Bars - - - - - - - - 159

1. As to hard *Plates* - - - - - - - - 159
2. As to hard *Bars* in combination - - - - - 168

RESULTS - - - - - - - - 175

CHAPTER IV.

ON THE RELATIVE POWERS, IN COMBINATION AND SEPARATELY, OF HARD PLATES OR BARS OF STEEL OF DIFFERENT DENOMINATIONS AND QUALITIES - - 185

Sect. I.—Of the Magnetical Powers, in combination, of Steel Plates (7·5 inches in length) of *different denominations*, but of the *same original quality* of Iron - - - - - 189

1. Experiments with Steel of *different denominations*, converted out of Stubs's Steel - - - - - - 189
2. Experiments with Steel of *different denominations*, converted out of best *Swedish iron*, marked hoop-L - - 195

Sect. II.—Of the Magnetical Powers, in combination and separately, of Steel Plates (7·5 inches in length) of *similar denomination*, but of *different qualities* of the original iron 196

CHAPTER V.

ON THE MAGNETICAL POWERS OF STEEL PLATES OF DIFFERENT MASSES, DENOMINATIONS, AND QUALITIES, AND MEASURES OF COMBINATION, PREPARED FOR THE NEEDLES OF SEA-COMPASSES, WITH THE EFFECT OF SPACING THE PLATES. - - - - - 202

Sect. I.—Experiments with Plates for Compass-needles of best cast-steel, tempered equally throughout, at a spring temper 204

Sect. II.—Experiments with Plates for Compass-needles, of superior qualities of steel of various kinds and denominations, made quite hard - - - - - - - - 208

1. Experiments with five series of 6-inch Compass-plates, being 0·56 inch broad - - - - - - - 209
2. Experiments with five series of 7·5 inch Compass-needles, of 0·75 inch in breadth - - - - - - 210

CHAPTER VI.

PAGE

ON THE EFFECTS OF THE *ANNEALING* OF HARD STEEL PLATES OF DIFFERENT KIND AND MASSES, ON THEIR MAGNETICAL PROPERTIES, BOTH SINGLY AND IN PAIRS - - - - - - - 214

Sect. I.—On the Effects of annealing Hard Steel Plates in boiling linseed Oil - - - - - - - - - 223

1. First Series of 24 Plates - - - - - - - 223

2. Second Series - - - - - - - - - 226

Sect. II.—On the Effects of annealing on hard Steel Plates, in hot Oil, at various degrees of temperature - - - - - 228

Sect. III.—On the Effects of annealing, at various Temperatures, on the Magnetic Powers of hard Steel Bars, single and compound, of the Horse-shoe form - - - - - - - 235

RESULTS - - - - - - - - 250

§ I. Results in respect to difference of *Denomination* in the *same quality* of hard Steel - - - - - 254

§ II. Results in respect to difference of *Quality* in the same *denomination* of hard Steel - - - - - 258

§ III. Results as to the Changes in Magnetic Properties produced in hard Steel of different denominations and qualities by annealing in boiling linseed Oil - - 260

§ IV. Effects of annealing on the Energy of hard straight-bar or plate Magnets, at degrees of temperature inferior to that of boiling Oil - - - - - - - 266

§ V. Results on the Magnetical Capacities and Powers of Steel Plates, or Bars, adapted for Sea-compasses, both single and compound, whether hard, or whether annealed at various temperatures, with the Effects of spacing the Plates - - - - - - - - 270

§ VI. Results in respect to the peculiar Effects of hardness and annealing on Magnets of the Horse-shoe form - 278

CHAPTER VII.

ON THE POWERS OF HARD STEEL BARS COMBINED IN VARIOUS WAYS, AS ALSO IN PROPORTIONAL MASSES, SO AS TO FORM COMPOUND MAGNETS OF LARGE DIMENSIONS AND OF GREATER LENGTHS THAN THOSE OF THE ORIGINAL ELEMENTARY BARS; WITH A PRELIMINARY INVESTIGATION CONCERNING THE METHODS OF DETERMINING THE RELATIVE POWERS OF MAGNETS OF DIFFERENT LENGTHS. - - 283

Case I.—Comparison of the Powers of various Bar-magnets of the same length (viz. six inches), as determined by the methods of Torsion and of Deviations, in order to the further verification of the method of Deviations - - - - 289

PAGE

Case II.—The Determination, experimentally, in Magnets of different lengths, of the relation of their respective deviating effects (at distances from the Compass proportional to their several lengths) to their actual directive powers - - - 292

Case III.—The comparative Capacities for Magnetism of equivalent, or similarly proportioned, Bars of Steel of different lengths, as Determined both by the method of Deviations and that of Torsion - - - - - - - . 295

Sect. I.—As to the proportional Powers of Magnets of different lengths, but in all other respects, both as to dimensions in breadth and thickness, and in quality and hardness of Steel, the same - - - - - - - - - 310

Sect. II.—As to the proportional Powers of Magnets combined as in the figures (plate iv.), compared with those in a single pile, or fasciculus - - - - - - - - 313

Sect. III.—As to the relation of the Powers of Bars of twelve and of those of eighteen inches when combined so as to constitute masses of the same form, dimensions, and weight - 315

Sect. IV.—As to the relative Powers of Combinations of twelve or eighteen inch bars, each kind by itself, and those of equal masses and dimensions composed of the two kinds, intermixed 316

Sect. V.—As to the relative Powers of various Combinations of Bars of the same description (except as to the length of the integrant bars) in *proportional* masses - - - - 317

Sect. VI.—As to the extent to which small Magnets, made quite hard, may be advantageously combined, with a view to the formation of larger artificial Magnets than have yet been constructed . - - - - - - - - 319

GENERAL RESULTS - - - - - - 324

CHAPTER VIII.

OF THE MAGNETICAL POWERS, RECEPTIVE AND PERMANENT, OF *CAST IRON*, BOTH IN SEPARATE BARS OR PLATES, AND IN VARIOUS COMBINATIONS OF PLATES - - - - - - - - 330

RESULTS - - - - - - - - 344

CHAPTER IX.

ON THE MEASURE OF PERMANENCY OF THE ENERGY IN STRAIGHT-BAR MAGNETS, BOTH SINGLE AND COMPOUND, AND OF DIFFERENT DEGREES OF HARDNESS, AS SELF-SUSTAINED, OR AS INFLUENCED ONLY BY TERRESTRIAL MAGNETISM - - - - 348

RESULTS - - - - - - - - 361

MAGNETICAL INVESTIGATIONS.

PART II.

INVESTIGATIONS CONCERNING THE LAWS OR PRINCIPLES AFFECTING THE POWER OF MAGNETIC STEEL PLATES OR BARS IN COMBINATION.

CHAPTER I.

AS TO THE POWERS OF COMBINATIONS OF MAGNETISED PLATES OF TEMPERED STEEL, IN CONTACT.

This important object of inquiry—as affecting both the directive power of compass needles and the energy of compound magnets—has been pursued to a much greater extent, and with a much larger variety and assortment of plates and bars, than it may here be necessary, or indeed useful, to describe.

In the whole, the powers in combination of about forty sets of plates or bars, have been carefully tried, in their respective series of from 2 to 192 together,—the total amount of magnetised pieces of steel, subjected to experiment, being scarcely less than from seven to eight hundred. And in several of the sets of bars or plates, the powers in combination were likewise determined for every amount of numbers, by successive additions of bar by bar, or plate by plate, up to the total quantity in the particular series.

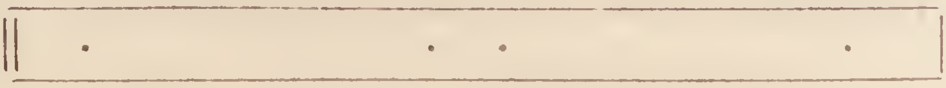
The numerous series employed were of various dimensions, from plates or bars of six inches, to two or even three feet, in length. They comprised steel of different qualities, and of the several conditions of hardness, from that which was perfectly soft to that which was "as hard"—to use the technical language of the smith or cutler—"as fire and water could make it."

The investigations concerning the relative powers in *combinations* of bars and plates of different weights, served to confirm the principles deduced from the experiments made with *single bars* in Part I. By applying the powers, indicated by the tangents of the deviations, to the diagram, Plate II., and correcting them by the scale of equation of deviations, the combinations of magnetic plates, as compared with the powers of single bars of the *same length*, were satisfactorily determined. The comparison of bars of *different lengths*, however, by this process, is, unless proximately, a matter of some difficulty.

A selection of the most characteristic and conclusive of these investigations will now be given. But, in this chapter, the selection will be only of a particular class of experiments, made with steel tempered in the same way, and of a similar degree of hardness. The resulting temper of these bars and plates was that of a spring temper *throughout* the mass,—each bar or plate being first made quite hard, from end to end, and then reduced to a blue colour, by a second heating, and there fixed.

As the results with steel plates of different lengths were found, in all essential points, correspondent—one example may be sufficient to be described in detail. And for this it will be convenient, for the purpose of comparison, to adopt the experiments made with the two-feet plates of tempered cast steel described in page 38. These plates, it may be remembered, constituted an uniform series of thirty-two in number—being 1·5 inches broad, and ·042 inch thick, and of the average weight of 2869 grains. The quality and temper of these plates were in general very equable; the deviating power on the compass, at one length distance, being, in the weakest, about 15°, and, in the strongest, 18° 30′, and the mean power of the whole, as tried separately, being 16° 10′.

These plates were all pierced with four corresponding holes, two about an inch from the centre, and two about an inch and a half from the ends, as represented in the annexed figure:



By these holes, any number of the plates could be readily combined together, and firmly screwed by means of brass pins, with screw nuts, put through them. The particular size of the plates was adopted for the purpose of a more satisfactory comparison with a pair of bars by M. Gauss, in the Royal Observatory at Greenwich, which appear to be of admirable quality and of very superior power. And this degree and mode of tempering was fixed on, at the early stage of my researches, as the first advance towards an improvement in the ordinary method of constructing compass needles and magnets, in this country,— the prevalent method consisting of a mere tempering of the ends, whilst the intermediate portions are either left in the original state of the steel, or, according to Capt. Kater's recommendation, *reduced* to the soft state. For even this alteration, in the usual method of constructing magnets, it was inferred, as the results already described abundantly indicate, would yield additional retentiveness; and, by virtue of that quality, would admit of a larger number of plates or bars being combined with advantage, than when tempered, after the ordinary method, by a moderate hardening only at the ends.

Corresponding with the steel plates now described—in length, breadth, and quality of steel —I procured from the same manufacturer four bars of about ·62 inch in thickness,—the two best of these being of a similar degree of hardness with that of the two-feet plates, and weighing 6·281 and 6·236 pounds of 7000 grains, or 6·258 pounds, the mean weight.

The modes of magnetising the plates and bars, and of determining their respective powers having been described in Part I. Chapters II. and III,—we are prepared for the consideration of the investigations, with this apparatus, concerning *the law of combination of magnetised plates of tempered steel, in immediate contact.*

The whole series of two-feet plates was, in the first instance, carefully magnetised to their utmost capabilities, by means of the two-feet bars above described, and by the process K.S. (p. 13), and their power of deviation determined at the distance of two feet, or one length, from the centre of the compass, on the "trial-board" (p. 31). One fasciculus was then formed of the whole of the plates, and the position of the plates changed by separating the fasciculus about the middle, and replacing the two portions in a different manner; so that those at first in the middle were brought to the surface, and those originally at the top and bottom were brought in contact at the middle. By this means, the whole of the bars were subjected to a very similar degree of violence. By a second trial of their deviating power, they were then separately tested, and, having been numbered, had their individual deviations registered. Two of the plates, however, being found considerably weaker than the rest, were rejected, and the subsequent experiments made without them.

Thirty of them being then remagnetised up to their original energy, they were progressively combined on the trial-board, and the magnetic power of the mass was examined (taking the mean deviation produced by the two poles of each series) at every addition from one to thirty plates,—beginning, in the first experiment, with the strongest plates, and proceeding in order with those of less and less tenaciousness; and, in the second experiment, taking the plates in the reverse order. The annexed Table shews the twofold series of experiments, together with the ratio of the increase of power,—and from the diminishing accession of energy observed, the absolute loss, by the deteriorating influence of the augumented tension, is finally determined.

No. of Plates.	First Combination.		ReverseOrder.		Ratio of Increase of Power.			
	Deviation.	Tangent.	Deviation.	Tangent.	Mean of Tangents.	Gain of Power.	Power of Plates Separately.	Loss by Increase of Mass.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
	° ′		° ′					
1	16·8	289	16·35	298	293	293	290*	—
2	29·3	555	27·48	527	541	248	580	39
3	38·20	791	36·16	734	762	221	870	108
4	45·6	1004	42·21	911	957	195	1160	203
5	51·0	1235	46·37	1058	1146	189	1450	304
6	54·18	1392	50·15	1202	1297	151	1740	443
7	57·23	1563	53·50	1368	1465	168	2030	565
8	59·12	1678	56·8	1490	1584	119	2320	736
9	60·52	1794	57·49	1589	1691	107	2610	919
10	61·56	1875	59·5	1670	1772	81	2900	1128
11	63·12	1980	60·3	1736	1858	86	3190	1332
12	64·4	2056	61·3	1808	1932	74	3480	1548
13	64·44	2119	61·49	1866	1992	60	3770	1778
14	65·23	2183	62·28	1918	2050	58	4060	2010
15	65·48	2225	63·4	1968	2096	46	4350	2254
16	66·10	2264	63·43	2025	2144	48	4640	2496
17	66·40	2318	64·10	2066	2192	48	4930	2738
18	66·58	2352	64·45	2120	2236	44	5220	2984
19	67·10	2375	65·10	2161	2268	32	5510	3242
20	67·19	2393	65·42	2215	2304	36	5800	3496
21	67·25	2404	66 0	2246	2325	21	6090	3765
22	67·33	2420	66·28	2296	2358	33	6380	4022
23	67·37	2428	66·48	2333	2380	22	6670	4290
24	67·54	2463	67·5	2365	2414	34	6960	4546
25	67·35	2424	67·21	2396	2410	— 4	7250	4840
26	67·26	2406	67·45	2444	2425	+ 15	7540	5115
27	67·31	2416	68·1	2477	2446	21	7830	5384
28	67·22	2398	68·16	2509	2453	7	8120	5667
29	67·17	2389	68·32	2543	2466	13	8410	5944
30	67·22	2398	68·54	2592	2495	29	8700	6205

* The average power of the different plates was about 16° 10′, tangent 290, from which average, column VIII. has been calculated—the loss by combination, column IX., being the difference of columns VI. and VIII.

The *advantage of combination* herein—in the yielding of additional magnetic power—becomes very obvious, when we compare the powers of the single bar magnet, (described at p. 101,) with an equal mass of these plates. One of the single bars weighing 6·236 lbs. was found, when fully magnetised, to acquire a deviating power of 54° 12′, of which the tangent is 1386; whilst fifteen plates, in close combination, of steel of similar quality, temper, and dimensions, being of nearly the same weight, (6·150 lbs.), exhibit a mean power of 64° 30′, the tangent being 2096.

After the completion of the series of experiments of the "Reverse Order" in this Table, the thirty plates were again separated into five parcels of six each as before (the six best plates being called series A, and the next in order of strength B, etc.), when their respective conditions, as shewn by their influence on the compass, were found to be as follow:—

Series.	Deviation at One Length Distance.			
	N. end.	S. end.	Mean.	Tangent.
	° ′	° ′	° ′	
A	46·4	46·14	46·9	1041
B	43·18	42·0	42·39	921
C	41·0	39·30	40·15	847
D	37·26	35·36	36·31	740
E	9·46	11·4	10·50	191

The sum of the tangents of these five series being 3740, whilst the highest tangent of the whole in one mass (thirty plates, col. v.) was only 2592—it was hence found that the deterioration by combination was not *altogether* permanent; but *partially recoverable on separation.* In this instance, the recovery of power as expressed by the difference of the tangents (3740—2592 = 1148) was equal to almost one-half of the entire power when the thirty plates were combined in one mass.

But this does not express the whole of the suppressed power, capable of being recovered by the individual separation of the plates. For the determination of the total quantity of power, which might be considered as in a state of *elasticity*, it was necessary still to ascertain the actual state of the plates, after their full combination, *separately*, so as, by the sum of their respective tangents, to determine the entire amount of power recovered.

Proximately, and sufficiently near for the purpose herein contemplated, trial was made of the individual powers of two series of six plates —series A and C. The power of each series in combination was first determined, *immediately before* the examination of the plates separately —because the whole mass, having lain for some days together in contact, had sunk below the power exhibited in the Table. The state of each of the two series in combination, and with their plates tried separately, is exhibited in the Table following.

Series A.			Series C.		
No. of Plates.	Mean Deviation.	Tangent.	No. of Plates.	Mean Deviation.	Tangent.
6 Plates.	42° 5′	903	6 Plates.	40° 45′	862
No. I.	11·10	197	No. I.	8·17	146
II.	11·2	195	II.	10·8	179
III.	9·43	171	III.	8·40	152
IV.	10·32	186	IV.	9·20	164
V.	10·7	178	V.	10·7	178
VI.	6·48	119	VI.	7·25	130
	Sum -	1046		Sum -	949

From hence we find a still further and considerable recovery of the power which had been in a state of elasticity in each of the series—the gain in series A, by total separation, indicated by the difference of the tangents 903 and 1046, being betwixt one-sixth and one-seventh; and in series C, about one-tenth.

Another circumstance to be noted, in regard to the remarkable effects of combination on the weaker bars or plates, is the practical fact, that such effects result not so much from inferiority in capacity of these bars, as from the measure of violence to which they are subjected. For it was always found, as indeed theory would have anticipated, that any change made in the number of the plates combined, made a material alteration in the comparative results; for the plates which, in the more numerous combination, almost entirely lost their power, when placed under less severity of tension or violence in smaller masses, were capable of retaining a very considerable proportion of their original energy. Thus the whole series (omitting two), as divided into five sets of six plates each, commencing with the six strongest, marked A, and gradually proceeding with the less tenacious ones to set E, and then being remagnetised, gave the following results:—

Set.	Mean Deviation of the two Poles. ° ′
A	53·25
B	50·45
C	50·56
D	49·45
E	48·15

So that the six plates of set E, which, when in the mass of thirty, had their total power reduced to about 9° 46′ = tangent 191, were found capable of retaining, with tolerable permanency, a power of 48° 15′ = tangent 1120, exhibiting, when in this more limited combination, a power nearly six times greater than before![*]

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[*] No account is here taken, or in any other of the deductions, as to *proportional powers* of magnets, mentioned in this Part of the work, of the "equation of deviations" described

Results, in all essential particulars analogous to those which we have been now describing, were obtained from experiments made with *bars* instead of plates. In one case, a series of ten bars of 13·8 inches in length, and each weighing rather more than a pound, was employed in a similar course of experiments to that constituting the leading subject of this Chapter; and, in another case, a combination of bars of two feet in length were tried in a similar way, but with no other essential difference in the phenomena being observed, except what was to be ascribed to inequalities in hardness, the effects of which *in combination* will have to be described more particularly in a subsequent chapter.

In the Diagram, No. 2, Plate III., the respective powers of various combinations of magnetised cast-steel plates, of twenty-four inches length, as placed in contact, are shewn by the course and position of the lowest and thickest curve; whilst the degree of superiority of the power of such plates, over equal masses in a solid bar, or two bars together, is exhibited in their comparative heights above the general line of abscisses.

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in Chapter III. Part I., and represented to the eye in diagram, Plate II., because the correction does not affect the *general results*, but only, in a slight degree, the numerical proportions.

RESULTS.

The general Results deducible from the foregoing investigations, as to the laws or effects of combination in magnetic bars or plates in contact—being applicable to the case of compound magnets generally—may be now advantageously collected, and, where needful, more particularly illustrated.

1. That any *single* bar or plate is more powerful or energetic, *proportionally*, than two or more corresponding and equal bars—that is, being bars of like dimensions, quality of steel, temper and mass.

This law is deduced from the invariable fact, that whatever may be the power of two or more bars combined in one mass, the amount of their separate powers is always greater. The proportion of *loss* by increase of mass, in the large series of thirty plates, is shewn in col. IX. of the table at page 103. Thus the power of two plates (Nos. 1 and 2) in *combination*, is expressed by the tangent 541 (col. VI.): the amount of their united powers, *taken separately*, being 580 (col. VIII).

Hence, if a compass or variation needle were to be constructed in which the *mass* was of no consequence, or which might be made indefinitely light, or requiring the least possible momentum—then a single magnetic plate, as thin and light as possible, would be the best. But as, for all ordinary uses in magnetical instruments, a given mass and momentum are absolutely necessary, for overcoming the resistance of the air and abiding its slightest motions: and as, when a compass card, collimater, or other substance or apparatus, is to be appended, a very considerable mass is generally requisite,—an important advantage is derivable from combination, as will forthwith appear.

The same law, though differing in quantity, applies to the comparison of single bars of various thicknesses or masses, being in all other respects alike—the thinnest bars being always more energetic, proportionally, than the thicker.

Thus, taking an example of the ratio of the power and the mass from the table at page 57, we find, in respect to the series T (tempered throughout), the tangent expressive of the energy of the thinnest bar to be 191; whilst that of the next in the series, being double of its mass, was only 307, or little more than one-half more. And comparing the thinnest bar (v.) with the thickest (i.) of the same series, we find, that, whilst the bar i. was nearly nineteen times the weight of the bar v., its energy when fully magnetised, compared with that of the other, was only in the proportion of 621 to 191 (according to the tangents of their respective deviating effects on the compass), or but little more than 3 to 1.

2. That a *combination* of magnetic bars or plates is always more powerful than any *single bar* of equal weight to that of the whole mass combined,—the bars compared being made of the same steel, and alike in their mode and degree of tempering, form, and dimensions, as to length and breadth.

Though, as just stated, a single bar is more energetic in proportion to its mass, than any number of equal and corresponding bars,—yet a combination of bars is always actually more powerful than the same mass in one bar, as stated generally in Chap. I. Part I. and as more satisfactorily appears by comparing the results of the table at page 103, with the powers of different single magnets—weight for weight. Thus, a pair of magnets, of the same length and breadth as the plates under examination, weighing 2·854 lbs. each, were found capable only of deflecting the needle of the compass, at two feet distance, in an angle of 35° 20′,—but seven plates, of the weight of 2·870 lbs, being very nearly the same mass, produced a deviation of 53° 50′ in one trial, (col. IV.) and of 57° 23′, in another (col. II.), the mean of the tangents indicating above double the power of either of the single bars.—In like manner, though not to the same extent of advantage, fifteen plates of the compound series exhibited a superiority of power, over a single bar of like nature and quality and weight, in the relation of 2096 (col. VI.) the tangent of deviation produced by the combined plates, and 1386, the tangent of the deviation produced by the single solid bar. A similar result, though not to an equal proportion of advantage, was obtained by a comparison of a series of plates, equal, in mass, to either of a pair of bars, by M. Gauss, in the Observatory of Greenwich—though these, I have intimated, are very superior and powerful for single bars.

Hence the corollary—that the directive power of any single needle, of the ordinary form and kind used in compasses, dipping needles, or variation needles, would be considerably augmented if the same mass were divided into, or combined out of, two or more plates of the same length and breadth. And as there is no needle or bar in ordinary use in compasses, or dipping needles, or other similar instruments, but what might be constructed in a compound form, these instruments, by this construction, are capable of receiving a much higher directive power than they usually have—independent of the advantages to be derived from better qualites of steel, and improved modes of hardening.

Combinations, however, of divided plates, transversely, do not afford the same advantage, but results of a converse kind. For any plate, so divided, is found to lose power on the whole. Nor do I find that any material advantage is derivable from the division of plates into narrow slips, longitudinally, so far as my experiments have gone.

3. That the *absolute gain* of power in the combined mass, by each additional plate or bar, *progressively diminishes.*

The diminution in the *proportional gain* of power, by adding bar to bar, is such, that, in the series of plates referred to, the last twenty-six, out of thirty, did not double the power of the first six. In a set of twenty-four smaller plates of greater proportional thickness, the proportional thickness being as 2·5 to 1, the *last twenty-two*, which were added to the fasciculus, did not quite double the power of the *first two.* Analagous results were obtained on trial of thicker bars.

The ratio of power in combinations of the two-feet plates (principally referred to in this chapter), laid on each other and in sensible contact, as examined by successive additions, *in sets of six plates* each, exhibits, very nearly, the geometrical series of one-half, one-fourth, one-eighth, one-sixteenth, the directive power of the first set of six plates being equal to *one*.

An inspection of the "mean of tangents" (table, p. 103), shews how nearly this ratio prevails. For convenience of comparison, the selection of powers may be thus exhibited—the power of the first six plates being called one.

No. of Plates.	Mean Tangent of Deviation.	Differences of Sets of Six.	Proportion of Additional Power.
6	1297	635	$\frac{1}{2}$, nearly.
12	1932	304	$\frac{1}{4}$, nearly.
18	2236	178	$\frac{1}{7}$, nearly.
24	2414	81	$\frac{1}{10}$, nearly.
30	2495		

Hence, were the bars or plates perfectly equal in quality of steel, dimensions, and tenaciousness of the magnetic energy, there would, no doubt, be a continual accession of power (though gradually diminishing,) *ad infinitum*; but, it is obvious, from the foregoing considerations and facts, that (could the contact be made perfect) no increase, short of infinite, would bring the whole power to two, or double the amount of that exhibited in the set of the two-feet plates herein referred to, by the first six plates.

This result, however, can only be considered, in the present instance, as the type of the general law; as in plates of a different quality or temper, and in bars of greater thickness, various modifications of the ratio must be expected.

Thus, it was actually found, that in the case of the other set of twenty-four smaller, but proportionally thicker plates, the *ratio* of the power with the mass combined, (comparing the effect of additional plates in *pairs*,) was different, though the result was in accordance with the general law. In this instance, considering the power of the first pair of plates as one, the addition of successive pairs presented, proximately, the following fractional, and somewhat irregular, series:—

$$\tfrac{1}{4},\ \tfrac{1}{8},\ \tfrac{1}{11},\ \tfrac{1}{14},\ \tfrac{1}{16},\ \tfrac{1}{19},\ \tfrac{1}{21},\ \tfrac{1}{26},\ \tfrac{1}{28},\ \tfrac{1}{30}.$$

And in the case of a series of *bars*, such as that of the bars of 13·8 inches mentioned at page 108, where each bar was of the weight of above a pound, the first bar gave a power, by itself, represented by the tangent of deviation 309; whilst the whole of the series, ten in number, gave no higher a power than that represented by the tangent 613, being scarcely double of that of a single bar.

4. That continued additions to a powerful combination of plates or bars, cease to be beneficial beyond a certain limited extent, because of the impracticability of obtaining a large series of such plates or bars perfectly alike. The *weaker* bars of a powerful series (that is, such as are inferior in quality of steel or of a lower temper), not only not adding to the magnetic energy of the whole mass, but sometimes, from their own polarity being reversed, absolutely injuring the total effect.

Column VII. of the table, at page 103, shews the gradually diminishing accession of power by each plate respectively; and col. II., in the first combination, shews that, a maximum, in that instance, was obtained by twenty-four plates, there being no increase, but an actual loss, by the addition of the last six.

Similar effects were observed in almost every case where a large number of plates or bars (not being perfectly hard) were combined in one series; so that a maximum of energy was generally obtained by a *portion* of the series, which maximum was found to be diminished, often materially, by the unfavourable action of the weaker plates or bars.

5. That some deterioration takes place in the *permanent* individual energy of all the bars or plates in combination, by every addition of power to the mass; the measure of deterioration in the separate bars varying with their difference of strength, or of their tenaciousness of the magnetic condition.

The term "strength" has been introduced in a former chapter (Part I. Chap. IV.) to express that quality of magnets by which the tendency to deteriorate, or return towards the neutral state, is resisted. Hence, the measure of the deterioration in different bars, exposed to the same degree of magnetic tension, is inversely as their strength. Strength and hardness, as a general law, seem to be accordant—increase of hardness yielding increase of strength. One anomaly, however, as to a particular case, will hereafter require to be considered.

This result, just above stated, is shewn by the condition of the several series of six plates after the combination (page 104), as well as by the condition of the individual plates tried separately: whilst the general agreement of different experiments for determining the degrees of strength in all the bars or plates of a given series, sufficiently establish the law.

As to the permanent deterioration of the plates tried separately, we find that the series A was reduced by being combined in the whole mass of thirty, from an average of 16° 10′, deflecting power, to 9° 54′; and series C, from an average of 16° 10′ to that of 9° 0′ (table at page 106).

In other cases, in which more powerful combinations were made, we find that some bars or plates, *in all respects to appearance alike*, lose their power entirely, whilst others suffer comparatively little by the combination.

6. That the relation of the deterioration of the magnetic energy to the quality of the plates, when combined in large masses, affords an easy and satisfactory process for *testing* the quality of each bar or plate so combined, in respect to its relative measure of tenacity or strength.

This method was employed, as already mentioned, for the separation of the two-feet tempered plates into the five different series comprising six plates each, numbered from A to E. Many other large bundles of plates were, in like manner, separated into their particular qualities, as to corresponding strength; similar results (as to all material differences of quality) being obtained on every repetition of the experiment. Particular examples of this mode of testing are given at page 40.

In the selection and trial of small bars or plates of an equal length, analogous results are obtained—with the advantage of being capable of ready comparison both with each other, and with a certain standard—by the use of the *test-bar* described at page 42.

Hence, we obtain important practical guidance, for a superior construction of compound magnets, of a two-fold character;—first, as to the inutility of making *large* combinations of bars on the ordinary plan of constructing compound magnets; and secondly, as to the importance of removing all the bars which have their polarity either reversed or neutralized by the combination, or which have their magnetism so reduced as to add nothing essential to the total energy.

In the case of the ten bars mentioned at the close of the illustrations of the result, No. 3, p. 114, two of the bars out of ten were found to injure the total energy to an extent of more than one-tenth, and so as to destroy the effect of two others.

7. That whereas the *weaker* plates lose the greater part of their power, or become absolutely neutralized, or even have their poles reversed, when subjected to the violence of large combinations—yet the same are capable of very considerable power and retentiveness of energy, if exposed only to an inferior degree of violence in small combinations.

The actual power retained in the five series of six plates each, after the combination of the whole in one mass, is shewn in the table at page 104; the state of each series, as indicated by its deflecting power on the compass at two feet distance, being as follow: —

A	B	C	D	E
46°·9′	42°·39′	40°·15′	36°·31′	10°·50′

But when the same plates, being remagnetized, were combined in no greater mass than that of their own series of six respectively—then their powers (p. 107) were these:

A	B	C	D	E
53°·25′	50°·45′	50°·56′	49°·45′	48°·15′

Hence, whilst the weakest set of plates E, was reduced, by the violence of the action of the whole series of thirty, to a deflecting power of 10° 50′, we find it capable of retaining such a power, when only combined to the extent of the six plates of its own set, as to deflect the compass needle, at the same distance, to an angle of 48° 15′—being a power, in the proportion of the tangents, six times greater than before.

8. That whilst magnetic bars in combination, (being a state of violence or constraint when similar poles are coincident,) suffer a *permanent* deterioration of power, from that of their individual capacity for magnetism when separate—they also suffer a further *transient* deterioration, as if the magnetic energy were in a state of elasticity—which proportion of deterioration is recovered on the separation of the bars.

The extent to which this influence prevails has been already shewn in the account of the experiments connected with the tables at pages 104 and 106. The recovery of power by the separation of the whole mass of thirty plates into five series of six plates, was nearly one-half; and the further recovery of power by the trial of the plates separately about one-eighth more!

Hence, the weaker bars which, when taken out of the mass, are found to retain a considerable portion of energy, may, whilst in the mass, be altogether without power; or may even have a reverse polarity, so as to cause an absolute loss to the mass.

Thus, the last six plates of the series of thirty (table at page 103), being the weakest of the series, actually diminished the power of the whole (see col. III.), though each of them, when tried separately, after the combination was taken down, was found still to possess a deviating power, in the original direction, of from 2 to 4 degrees.

CHAPTER II.

ON THE POWERS OF COMBINATIONS OF MAGNETISED STEEL PLATES, SEPARATED BY LIMITED SPACES.

1. When it was found that so much of the aggregate power of the separate plates or bars, in a series of magnets, was lost by the combination in one mass *in contact*—it was but natural to anticipate that, an inferior deterioration would take place by a combination of a less concentrate description,—the plates or bars being kept *out of contact* by substances, not susceptible of the magnetic condition, interposed.

The effect of such separation, which I had long ago determined in a limited degree, I now proceeded to investigate by means of the series of thirty tempered plates. For this purpose a sufficient number of blocks of wood of different thicknesses—constituting circular discs 1·5 inch in diameter—was prepared,—each being perforated in the centre, so as with facility to combine along with the steel plates; whilst additional wires, furnished with screw nuts, were also provided, adapted by their lengths to the extent of separation which might be required in the several masses so combined.

The first and most elaborate investigation—as to the effect of separation on the progressive accumulation of power in the whole mass of plates—was made with interposed discs of 0·14 inch (about one-seventh of an inch) in thickness. As however, the series so separated—like the frame saws in a saw-mill—spread out to the width of several inches (and in subsequent experiments, with thicker discs or blocks, sometimes to the breadth of more than a foot)—it was found conducive to accuracy to test their powers at *two* lengths, or four feet distance, instead of one length, as in the former experiments. At the same time, for the advantage of comparison with the results obtained at one length distance, occasional trials—in the progress of combination—were made of the action of the series on the compass at one length; which, with other comparative experiments, by means of various combinations and bars of the same length, afforded the means of determining, experimentally, the precise ratio, unequated, of the directive forces for distances of one and two lengths. It may be convenient, perhaps, to give this determination before proceeding with the investigation proposed.

The following table exhibits a selection of the comparative deviations, at one and two lengths' distance, of different combinations of two-feet plates.

No. of Plates in Combination.	Deviation at one length.		Deviation at two lengths.		Ratio of two lengths to that of one length; one length being = 1000.
	Mean.	Tangent.	Mean.	Tangent.	
	° ′		° ′		
6	55·50	1473	15·32	278	189
6	55·20	1446	15·15	273	189
6	54·46	1416	14·55	266	188
12	67·30	2414	24·5	447	185
18	71·35	3003	29 40	570	190
24	74·22	3574	33·48	669	188
1	15·52	284	3·5	54	190
30*	68·30	2539	25·50	484	191
			Mean .	....	188·75

* The last combination (that of 30 plates) was in *contact*, all the others were separated by discs of wood.

Hence, the ratio of the directive powers of bar magnets, for one and two lengths distance from the compass (as thus determined for magnets of two-feet in length), appears to be as 1000 to 188·75. Theoretically, the proportions might seem to be a little different,—being inversely as $N^2—R^2$: $n^2—r^2$, N being the near pole of the magnet, and R the remote pole, at *one* length distance; and n the near, and r the remote pole, at *two* lengths distance. For this proportion, calling the power at one length 1000, would give $\frac{5}{27}$ for that at two lengths, or as 1000 to

185·2. The difference is in some small degree to be ascribed to the want of application of the equation of the tangents of deviation, described in Part I. Chap. III., but mainly arises, I presume, from the circumstance of the *polar* or *focal* lengths of the bars being different from their measured lengths. For were the entire magnetic forces of the bars concentrated at the very extremities, the ratio, corrected for the equation of tangents, must have been according to calculation; but as the resultant of the magnetic forces, in either half of the bars, constitutes a point or *focus* of attraction *within* the extremity (which by other experiments I found to lie at about one-twelfth of the length of the bars from the ends), the comparison cannot exactly hold, unless the two distances were those of *focal* lengths, instead of actual lengths of the bars.

Thus provided with the means of comparing the deviations obtained at the different distances referred to, the results of a progressive combination of the plates, with interposed discs of ·14 inch, become available for the object contemplated. The deviating powers of the series, so combined, on the compass at two lengths or four-feet distance, were as follow:—

No. of Plates.	Mean Deviation	Tangent.	No. of Plates.	Mean Deviation	Tangent.
	° ′			° ′	
A 1	3·5	54	16	28·4	533
2	6·39	117	17	29·9	558
3	9·6	160	18	29·40	570
4	11·32	204	D 19	30·30	589
5	13·47	245	20	31·18	608
6	15·32	278	21	32·6	627
B 7	17·8	308	22	32·31	637
8	18·39	338	23	33·11	654
9	20·5	366	24	33·48	669
10	21·34	395	E 25	34·10	679
11	23·2	425	26	34·37	690
12	24·5	447	27	34·57	699
C 13	25·15	472	28	35·9	704
14	26·28	498	29	35·38	717
15	27·6	512	30	35·55	724
	Closed into Contact,		30	25·50	484

Here then—without carrying out the comparisons with the table at page 103, of the progress of increase over the former mode of combination—the advantage of the separation becomes sufficiently obvious by the mere comparative results of the entire series of thirty plates, as separated by 0·14 inch blocks, and as closed into contact. For looking merely at the foot of the above table, we find the power of the series, when *separated* (as represented by the tangent), to be 724, and, when in contact, only 484,—exhibiting a gain in energy, by this very limited separation, of about two-thirds of the original power.

2. The effect of separation at other, and greater, distances, was now tried by means of the same plates, and these combined in the same

order,—that is beginning with the series A, or strongest bars, and proceeding progressively with the series B C D, etc. The actual, as well as comparative, results, observed under different measures of separation, are the most compendiously exhibited in a tabular form.

Comparative powers of two-feet steel plates, magnetized to the limits of their capabilities, when separated by different-sized discs or blocks — the distance of the plates from the compass being two lengths or four feet, and the mean deviating power of one plate being 3° 4′.

No. of Plates.	In Contact.			Discs of 0·14 Inch.			Blocks of 0·28 Inch.		
	Mean Deviation.	Tangent.	—	Mean Deviation.	Tangent.	Gain over Cont^{t}.	Mean Deviation.	Tangent.	Gain over Cont^{t}.
	° ′			° ′			° ′		
3	8·32	150	—	9·6	160	10	*9·12	162	12
6	14·34	260	—	15·32	278	18	16·0	287	27
12	20·58	383	—	24·5	447	64	26·25	497	114
18	23·45	440	—	29·40	570	130	—	—	—
24	25·10	470	—	33·48	669	199	—	—	—
30	25·50	484	—	35·55	724	240	—	—	—

No. of Plates.	Blocks of 0·40 Inch.			Blocks of 0·48 Inch.			Blocks of 1·0 Inch.		
	Mean Deviation.	Tangent.	Gain over Cont^{t}.	Mean Deviation.	Tangent.	Gain over Cont^{t}.	Mean Deviation.	Tangent.	Gain over Cont^{t}.
	° ′			° ′			° ′		
3	*9·16	163	13	9·18	164	14	9·40	170	20
6	16·28	296	36	16·54	304	44	17·44	320	60
12	27·38	524	141	28·39	546	163	30·51	597	214
18	—	—	—	37·48	776	336	—	—	—
24	—	—	—	43·45	952	482	—	—	—
30	—	—	—	47·41	1098	614	—	—	—

N.B.—The "gain over contact," is the difference of the tangents of each division, and the tangent of deviation when in contact. Thus, 150 (col. iii.)—160 (col. vi.)=10 (col. vii).

* These are not actual observations, but approximate numbers.

That a comparison of these various results may be more readily made, and an accurate idea conveyed, by mere inspection, of the proportion of advantage gained by the system of combination—the relations of the several investigations have been represented by the diagram No. 2, in Plate III. For the power of the combined plates, in the progressive augmentation of their number, is very well represented, after the manner adopted in a former case, by a curve—of which the abscisses represent the number of plates, or mass of steel in the combination, and the ordinates the tangents of the angles of deviation for the several masses. The diagram exhibits the powers of various combinations; but those with which we have at present to do, are the results contained in the foregoing tables—the different continuous curves, representing the powers of the plates in their respective degrees of separation,—the lower and blacker curve (before referred to) shewing the comparative power of the same magnetized plates when combined in *contact*.

Before I proceed to deduce the general results from this mode of spaced combination, I may mention the effect of *partial* contact and partial separation—such as the loss of power when the plates, which had been put up in the usual mode of spacing, were brought into contact at one or both ends. For this investigation the thirty plates were combined in separate series of six plates each, in the manner before described, with 0·14 inch discs interposed. Their powers on the compass, at one length distance, being respectively ascertained, the effect was noted when the discs at the ends of the series were removed, and the plates pressed together at the ends, whilst the mass rested on the trial-board in the position in which its power was determined; and, subsequently, the centre discs were also taken away, so as to bring the six plates into contact throughout. The results, at one length distance from the compass, were as follow:—

Series.	Separated by Discs.		Closed at the ends.		Contact throughout.	
	Mean Deviation.	Tangent.	Mean Deviation.	Tangent.	Mean Deviation.	Tangent.
	° ′		° ′		° ′	
B	54·27	139·9	53·47	135·6	53·1	132·8
C	53 5	133·1	51·56	127·7	51·26	125·4
D	55·53	147·6	54·37	140·8	53·46	135·6
E	51·17	124·7	50·4	119·5	48·54	114·6
	Mean	136·3	…………	131·1	…………	127·3
		Loss per cent…….		3·9	Loss per cent. 6·6	

Here the average *gain* by separation, and *loss* by partial or entire contact, are distinctly shewn. Even in this limited quantity of plates, amounting only to six in each series, we find the advantage of entire separation by means of thin discs (0·14 inch) over *contract at the ends*, was as 136·3 to 131·1, or as 100 to 96·2; and the advantage of entire separation over entire contact, was as 136·3 to 127·3, or as 100 to 93·4. In this case, the separated series is found to be only about one fourteenth part more energetic than the same series in contact; but when larger series are employed, the difference becomes much more considerable, so that thirty of these plates, separated by nearly half-inch spaces, attain a degree of magnetic energy more than *twice* that of which the same plates are susceptible when in contact.

RESULTS.

The general Results derived from the investigations described, or referred to, in this chapter, were, in the main (except as to measure or quantity), similar to those yielded by the experiments on the combination of the same plates in contact. The following modifications, however, or additions, may be mentioned.

1. That the *quantity of gain* in power of any combination of plates or bars, over equal masses in a solid bar, is greater, where the plates or bars combined are prevented from coming into contact; and this augmentation of *gain* in power, *improves*, as the spaces betwixt the plates or bars are enlarged.

This result, generally, was fully anticipated; but the proportion of effect due to different measures of space betwixt the plates could only be determined by actual experiment.

Comparing the results of the table at page 124, we find the progressive gain, by the interposition of thicker discs or blocks, was such, that whilst a combination of six plates with spaces of 0·14 inch exhibited a power 6·9 per centum greater than that of the same in contact, —these six plates with spaces of one inch gave 23·1 per centum more power than when in contact. That a series of thirty plates, with 0·14 inch discs, exhibited a gain, in the whole, of 49·6 per cent., and with blocks of 0·48 inch, obtained no less than 127 per cent. more power, than when the same were in visible contact.

The Diagram, No. 2, Plate III., exhibits to the eye the several relations of the power of the plates, as combined in *contact*, or as spaced with interposed discs or blocks of 0·14, 0·48, and 1·0 inch.

2. That a *larger number* of plates may be combined with advantage, and a greater measure of directive energy obtained, by the separation of the plates or bars—the proportion of increase of attainable power, and the extent of advantageous combination, having relation, with plates of the same *temper*, to the measure of the spaces betwixt them.

Hence it is evident, that the spaces might be so increased, that the deteriorating influence of the plates on each other would cease to be at all considerable,—and so that, if additions continued to be made to the utmost extent of *practicable* combination, each additional plate of similar *strength*, would add a portion to the general amount of power.

3. That the measure of *permanent deterioration* in the magnetic energy of the several plates, is respectively less, in proportion as the density of the mass is diminished by separation.

4. That *weaker plates* can be combined to a much greater extent, and with superior advan-

tage, when separated by discs or blocks, than when the same are in contact.

5. That a *partial separation* — such as that of the middle of the plates, the ends being in contact — yields an additional energy to what is obtained by entire contact,— the additional energy, however, being by no means so considerable as when the separation is complete.

The proportion of advantage by separation throughout, over partial separation in the middle only, in the case of combinations of six plates, has already been mentioned, as derived from the investigations in the Table at page 126; but that proportion becomes greater as the extent of the combination increases.

For in the case of *entire* separation, we find, from the particulars in the Table at page 124, that whilst twelve plates, separated by blocks of 0·48 inch, exhibited a power, compared with the same in contact, of 546 to 383; thirty plates so separated, compared with the same in contact, obtained a power in the proportion of 1098 to 484. So that the advantage of this measure of separation was,—with three plates about 9·3 per cent. more than the energy in contact; with six plates 15·8 per cent.; with twelve plates, 42·5 per cent.; and with thirty plates, 127 per cent. gain over the power in contact.

Hence a similar improvement, though inferior in degree, was expected to be obtained by *partial* separation, over contact, *with larger combinations* than those above described. In the case of thirty plates in combination, the advantage of partial separation, over contact, as well as the disadvantage of *any contact*, in comparison of entire separation, is strikingly shewn by this one experimental fact:—that the thirty plates, which, in entire contact, had only a deviating power (at two lengths from the compass) of 25° 50′ (tangent 484), previously exhibited a power of 31° 50′ (tangent 621), when only *one end* of the plates was closed—being the end most remote from the compass;—whilst the same series, when fully separated by discs of 0·14 inch, had, in the first instance, before any contact was permitted, a power of 35° 55′ (tangent 724). See Table at page 123.

In this experiment, the great disadvantage of closing the ends of the combination of plates, especially of a powerful combination, is remarkably proved by the comparison of the powers of the series when entirely separated, and of the same when closed at one end, and that the most remote from the compass,—the reduction of deflecting energy, in this case, being in the proportion of the tangents 724 and 621.

CHAPTER III.

ON THE RELATIVE POWERS OF COMBINATIONS OF MAGNETISED STEEL PLATES OR BARTS, AS AFFECED BY DIFFERENCES IN THE DEGREE OF HARDNESS OR NATURE OF THE TEMPER.

When these Investigations were originally made, I was not aware that some of our early magneticians had recommended hard steel to be employed in the construction of artificial magnets, —thus indicating that there were certain advantages, especially with relation to the *permanency* of the power, to be derived from such a condition. Of the actual determination, however, of the fact of any other advantage from absolute hardness, than that of permanency, or of the actual investigation of the relative effects of various degrees of hardness,—I have not met with any record. A certain degree of hardness, for compound magnets, had been mentioned as desirable; such as that produced by tempering the steel at the heat of "cherry-red" (a moderate degree of hardness only); but this recommendation rather went *against* the supposition of greater degrees of hardness than that being generally advantageous.

The field of investigation, therefore, entered upon in this chapter, may still, I apprehend, be considered as new,—so far, at least, as regards the determination of the actual and comparative influence of the various degrees of hardness or qualities of temper, by which the more important properties of magnets may be influenced.

Much, indeed, of this portion of our subject, has been partially involved in the investigations in Part I.—"on the ratio of the power of magnetised steel bars, as modified by difference of tempering;" and many of the general results might, by analogy, have been anticipated. But still, the investigations on the actual effects of tempering and hardness, on *combinations* of steel plates and bars, will not, I hope, be found unimportant, especially as affording additional information of much practical consideration in the construction and improvement of magnetical instruments.

A summary of, or selection from, the investigations made on this subject—with bars or plates in several distinct conditions, as to temper—will afford all the information, as yet obtained, which has appeared to me to be of sufficient importance to be recorded.

1. *Of the relative powers of combinations of magnetised steel plates, as affected by* changes *in the temper of* the same *series of plates.*

Captain Kater, in his investigations for his Bakerian lecture, published in the Philosophical Transactions, arrived at the conclusion, that increased energy was given to the small magnets designed for compass needles, by *reducing* the hardness in the middle of the needles after their having been tempered at a blue throughout.

As, however, the investigations of this scientific experimentalist had been chiefly made with small masses of steel, and, generally, with thin plates, it by no means followed that this was a general law,—as we shall hereafter find it did not in the case of other results obtained with like masses. On the contrary, it will be abundantly proved, that the *principles* which affect the proportionate powers of small and thin magnets, of unequal degrees of hardness or difference of quality, will not apply to a comparison of the powers of large masses, under the like conditions.

In order to determine what might be the effect, of reducing the hardness of a combination of tempered steel plates, on their magnetic capabilities, I made trial of different sets, some being two feet in length, some 8·7 inches, and others six inches;—the plates of each set being of corresponding size, quality, and temper.

The first set, subjected to investigation, consisted of plates of ordinary steel, cut out of a parcel obtained at the shop of an ironmonger and tool-maker in London, 8·7 inches in length, ·65 inch in breadth, about ·035 inch in thickness, and weighing, on an average, 370 grains. These were 24 in number, consisting of a selection, out of the original series, of the weaker plates, or those of an inferior degree of retentiveness. Their degree of hardness was, I considered, that of a low spring temper, pretty regular throughout.

The whole series, being strongly magnetised, was first laid together in one fasciculus, and their order of tenacity, for magnetism, individually determined. Each plate, having been previously marked with a separate number, had its several capabilities registered.

Two sets of experiments were then undertaken with this series, in their *original condition* as to temper, arranged in their order of retentiveness or strength, for the determination of the progressive accumulation of power; first, commencing with the strongest plates, and next, after their being remagnetised, commencing with the weakest, or in the reverse order of the series.

These experiments being completed, the whole of the plates were then *reduced* in the middle to the extent of about six inches, by laying them in succession across an iron bar, heated to redness, till the surface above became of a deep purple colour, and then letting them cool slowly,—

leaving nearly one and a half inches of each end in the original state. In this condition they were re-magnetised, and their powers, in progressive combination, again determined.

Twelve of the series, from the weakest side of the entire fasciculus of plates, were then heated *throughout their length* in the same manner as before, and their powers also examined.

The whole of the results are given in the following table. The first division exhibits the actual and comparative powers of the whole series, commencing with the strongest plates, in two different conditions,—that of their original temper, and that of their supposed *reduced* state, after being heated in the middle. The second division shews the powers of the series in a reverse order, commencing with the weakest plates, in their original state as to temper—with the comparative powers of a part of the same series when reduced *throughout* their length, by heating as before.

TABLE exhibiting the Comparative Powers, in combination, of the Series of smaller Plates, 8·7 inches in length, in three several states of temper.

No. and Order of Plates	Power in original tempered state.		Power when reduced in the middle.		Order of Plates	Power in the original temper.		Power when reduced throughout.	
	Mean Deviat.	Tangent	Mean Deviat.	Tangent		Mean Deviat.	Tangent	Mean Deviat.	Tangent
	° ′		° ′			° ′		° ′	
1	9·42	171	10·56	193	24	8·52	156	8·58	158
2	15·55	285	17·54	323	23	14·22	256	14·29	258
3	18·21	332	20·46	379	22	16·49	302	17·9	309
4	19·22	351	21·55	402	21	18·0	325	18·33	336
5	21·7	366	23·34	436	20	19·26	353	19·54	362
6	21·38	397	23·42	439	19	20 13	368	20·54	382
7	22·25	413	24·31	456	18	20·49	380	21·34	395
8	22·44	419	25·5	468	17	21·15	389	22·6	406
9	23·33	436	25·32	478	16	21·58	403	22 40	418
10	23·30	435	25·47	483	15	22·27	413	23 31	435
11	23·55	443	26·17	494	14	22·56	423	24·4	447
12	24·25	454	27·2	510	13	23·27	434	24·48	462
13	24·45	461	27·43	525	12	23·50	442		
14	25·18	473	27·53	529	11	24·26	454		
15	25·38	480	28·15	537	10	24·42	460		
16	26·12	492	28·44	548	9	25·22	474		
17	26·30	499	29·0	555	8	25·43	482		
18	26·43	503	29·25	564	7	26·7	490		
19	27·13	514	29 52	574	6	26·40	502		
20	27·35	522	30·16	584	5	27·13	514		
21	27·42	525	30·23	586	4	27·38	524		
22	28·4	533	30·44	595	3	27·56	530		
23	28·28	542	31·15	606	2	28·18	538		
24	28·41	547	31·16	607	1	28·47	549		

The results of these several effects of heating, and (as it is assumed) reducing in temper, were not such as had been expected. For, from all foregoing experiments, I had been led to conclude, that, whatever might have been the effect of the reducing of the temper in single thin plates, or small masses, the effect in *combination* would have been to diminish the energy of the plates,—whereas a considerable gain of power was yielded by the heating of the middle of the plates, and some increase beyond the original power, though not to the same extent, was produced by a corresponding heating of the plates from end to end.

This discrepancy with the results previously obtained, having occasioned some embarrassment and misgiving as to the correctness of the principle I had considered certain, — namely, as to the advantage of an equable hardening throughout for bearing the tension of powerful combinations of magnetised bars or plates,— I sought to verify the newly obtained result, or to determine the cause of the *apparent* discrepancy, if not real, by a trial of the same process with a set of larger, and, proportionally, thinner plates. For this purpose I selected a set of six plates of two feet in length (that of series E referred to at page 104), and reduced the temper in the middle of each plate, leaving about three inches in length, at each end, in its original state. This was done in the same manner and proportion as in the first alteration made in the temper of the smaller plates, just spoken of, and by which treatment the most considerable increase of power in these plates had been yielded.

The change which took place in the power of each plate by this alteration of temper, as ascertained by the deviation produced on the compass at the distance of two lengths, or four feet, was not the same as that indicated by the former experiment, as here distinctly shewn :—

No. of the Plate.	Mean Power of Plates separately.	
	In their original state.	After being reduced in the middle.
1	3°·17′	3°·15′
2	3·0	2·53
3	3·1	2·55
4	3·8	2·53
5	3·0	2·59
6	3·8	3·7
Mean . .	3·5⅔	3·0⅓

This result, it will be perceived, appears to be the very reverse of that obtained by a similar mode of treatment on the set of 8·7 inch plates. For in that case, a partial heating of the plates in the middle, until they assumed a purple colour, augmented the capacity for magnetism of the whole series, when in combination, in the ratio of 607 to 547, or about one-tenth gain; whilst a similar heating of a dozen of the same plates from end to end, gave an increase of power, in the combination, over that of their original temper, in the ratio of 462 to 434, being a little more than one-fifteenth gain. But in this subsequent experiment with the set of six two-feet plates, a *loss* of power was sustained by every one of the plates, amounting, on an average, to about one thirty-sixth part of the original energy. A trifling loss was likewise observed to have taken place in the tenaciousness of the plates,—the power of the six plates in combination and contact, after the reduction of the temper, being less than that of the same plates in their original condition.

In order, however, to investigate still further the cause of the discrepancy of the results with the smaller plates, I ordered another set of two-feet plates of best cast-steel, comprising two descriptions, as to their kind of tempering. They corresponded, as to dimensions, with the series of thirty plates, so much already treated of, except as to thickness,—these new ones being of the average thickness of ·057 inch, and of the weight of ·545 pound,—the former averaging ·042 inch in thickness, and ·410 pound weight. This new set of plates consisted of twenty-four in number, of which sixteen were tempered equably throughout, a little *harder* than the former, and the other eight were tempered in a similar way at the ends, being *softer* in the middle. The average weight of the plates of each kind was very nearly alike.

All these plates being magnetised fully, by at least four strokes (two on each side) by process KS, were examined as to their deviating powers severally, at the distance of two lengths, or four feet, from the compass; each kind was then tried in combination, separated by discs of ·14 inch (the sixteen harder plates in two fasciculi of eight), and so their various powers were determined. After some other experiments, hereafter mentioned, the twenty-four plates were placed in one mass in *contact*, with similar poles coincident, not in their original order, but with the plates of each series of eight regularly alternating, so that the whole were thoroughly changed and intermixed. The power of each plate, after being subjected to this state of violence, was finally examined, by which the relative strength or tenacity of all the plates for the magnetic condition was found, and a mean of comparison, betwixt the two kinds of plates, as to tempering, obtained. The last column in each division of the annexed table, shews the individual power of each plate after the final combination,—the other columns their powers when first magnetised (determined separately), as also their powers in combination when separated by the discs.

Equably Tempered Plates.								Plates Softer in the Middle.			
No. of the Plate.	Separate mean deviating Power.	Mean Power in combination.	Separate Power after contact of the 24 Plates.	No. of Plate.	Separate deviating Power.	Mean Power in combination.	Separate Power after contact.	No. of Plate.	Separate deviating Power.	Mean Power in combination.	Separate Power after contact of the 24 Plates.
	° ′	° ′	° ′		° ′	° ′	° ′		° ′	° ′	° ′
1	3·45	3·45	2·15	9	3·34	3·34	1·55	17	3·38	3·38	1·25
2	3·9	6·35	1·50	10	3·8	6·9	1·15	18	3·17	6·28	0·16
3	3·33	9·25	0·50	11	3·40	9·10	2·15	19	3·31	8·58	1·42
4	4·25	12·15	3·4	12	3·42	11·43	2·20	20	3·26	11·19	0·47
5	3·37	14·27	2·5	13	4·7	14·17	2·47	21	3·18	13·8	1·38
6	3·31	16·10	1·16	14	3·33	16·15	1·17	22	3·30	14·55	0·45
7	4·40	18·25	3·10	15	3·11	17·35	0·47	23	3·24	16·20	1·30
8	4·15	20·15	2·55	16	3·11	18·58	1·15	24	3·27	17·55	1·0
Mean	3·52	. .	2·11	. .	3·31	. .	1·44	. .	3·26	. .	1·8

Here we find a very decided difference in the two kinds of plates (both as to individual capacity for magnetism, and as to power in combination), in *favour* of the plates tempered or moderately hardened throughout. The separate powers of the softer plates, indeed, were very nearly equal to those of the second series; but after being subjected to the violence of contact in the whole mass, their inferiority became very apparent. The mean power of the softer plates, separately, compared with that of the second series of harder plates—was as the tangent of the angle of deviation, 3° 26′, to tangent of 3° 31′; but after combination, as tangent of 1° 8′ to tangent of 1° 44′.

The inequality in the *strength* of the different series, however, became more apparent, when they were *tested* by being all combined in one fasciculus, with similar poles together. The resulting powers of the several series then tried separately—that is in sets of eight plates each—were found to be very dissimilar, the first set producing a deviation in the needle of the compass of 14° 7′, the second of 12° 5′, and the third (or that soft in the middle) of 8° 5′.*

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* It is proper to be noted, that an undue application of these results, with reference to the particular question under consideration, be not made, that the softer condition of the middle of some of these plates was, probably, not produced by a second heating, or *reducing*, as in the former cases considered in this section.

Notwithstanding the accordance of all these latter experiments, made with two-feet plates, with the results of investigations described in the former chapters,—the difference in the case of the smaller plates yet remained unexplained. One or other of these conclusions, therefore, seemed inevitable,—either that the heating of moderately tempered bars until a change of colour appears, does not necessarily *reduce* the temper, or degree of hardness; or that such reducing of temper, in *certain cases* (the exact conditions of which are not yet determined), instead of diminishing, serves, as Captain Kater had concluded, to augment the capacity of steel for magnetism.

Not being able to ascertain, whether the portions that had been discoloured by being heated were, or were not, reduced in temper,—I considered that I might determine satisfactorily, by another course of procedure, whether the reduction, if any, was at all considerable.

In order to the determination of this fact, I took a portion of the 8·7 inch plates (nine in number), which had been, apparently, the most reduced. These I put together into an ordinary kitchen fire, until heated to the apparent degree of the bright cinders amid which they were placed. On being removed, they were laid on the hearthstone to cool.

The magnetic condition was now found to have undergone a very great change. Magnetised to the utmost, their deviating power, separately, was, on an average, reduced from about 9° 17′ (the power in the original temper) to about 6° 55′; whilst their power in combination was reduced very nearly one-half! Or taking the proportions conversely, in respect to the superiority of one condition over another, we find, that although, in the former experiments, nine of the plates in combination which had been moderately heated in the middle, obtained an accession to their original power of about one-tenth; yet, nine of the same plates, as shewn by this latter experiment, when in their original condition of temper, had a greater power than the same had when heated to redness in the kitchen fire, in the proportion of 418 to 225, or nearly nine-tenths more

Hence it becomes obvious, that, whatever may have been the change produced in the condition of the plates, by the former mode of heating on a bar of iron, the *quantity* of that reduction must have been very small.

The actual effect of this small measure of heating, on the arrangement of the particles of the steel in that particular state of elastic temper, I was disposed, at this point of the investigation, to imagine, might perhaps be only just sufficient to disturb, or raise, as it were, the crystalline structure of the ferruginous elements, which, in the case of the larger and thinner plates, subjected to the same treatment, had been not only disturbed, but partially changed or *reduced!*

Another view of the difficulty, however, now occurred to me, by which, what had hitherto proved so embarrassing, seemed likely not only to be resolved, but the principles elsewhere deduced, established and confirmed.

It has before been shewn, from the experiments described in chap. v. Part i., and by the principles exhibited in chap. viii., that the energy which a magnet, unsustained by a keeper or conductor, is able to receive and *retain*, is dependent on the measure of concurrent action of the two qualities of capacity for magnetism, and of tenaciousness or strength. The first quality is possessed in the *greatest degree* by *iron*, especially by iron of the finest and softest descriptions; and next by *steel*, of the finest kinds and in the softest state. The second quality, which is scarcely possessed at all by iron, and in a very moderate degree by soft steel, belongs most eminently, in respect of steel, to that of the greatest hardness; and occurs, intermediately, in a certain relation to the degree of hardness. Hence these two qualities have a varying influence on the power of a magnet, according as the mass is enlarged or the hardness increased; so that in small masses and very thin plates, *capacity* gives the pre-eminence, and in large masses or thick bars, *tenaciousness,*—inasmuch as in these, where the magnetic tension or violence is great, the power of sustaining the tension is of the first importance.

We find, therefore, as has been before shewn, that there are particular limits within which each quality, as it affects merely the primary energy immediately after being magnetised, has its pre-eminence. If the tension of the magnet, or combination of magnets, be not beyond a certain limit, the moderate tempering will outvie that of greater hardness; if beyond that limit, the increased hardness will be superior.

Now the difficulty under consideration might, it appeared probable, be resolvable into this particular case—viz. a case in which there being no great tension or violence of combination, the gain of capacity, by the slight and partial reduction of the hardness, had not been overcome by the effect of the diminished tenaciousness. For if this were the fact, then the apparent difficulty would resolve itself into actual conformity with the previously determined principles on which the energy of magnets of different masses and degrees of hardness is dependent.

And that this was really the fact, in the special case contemplated, this consideration rendered probable, that, although the number of plates combined was so considerable (twenty-four), yet their united energy was but of very moderate amount,—so moderate, indeed, that (as the inspection of the table at page 137 will shew) the total effect of the whole series was but little more than *three times* that of a single plate!

The fact, however, promised to be determined by another mode of investigation, in which the inquiry should be,—whether, in cases where an augmentation of energy was yielded by heating or reducing the plates in the middle, that reduction of temper was not accompanied by a diminution in tenaciousness or strength? If so it should prove, then would the present case come strictly within the principles before laid down.

In order to the determination of this inquiry, I selected five plates of tempered steel, of the uniform length of six inches, of the breadth of three-eighths to one-half inch, and of different thicknesses. They were all supposed to be of a spring temper throughout. The maximum power of each of these plates was first determined, and the reduction, after application to the test-bar (H), ascertained on the trial-board.

They were then placed on a piece of iron, heated to redness, till the colour near the middle partially changed to a blue, when they were plunged into cold water; the maximum power of each, with the effect of the test-bar on it, was again determined. Finally, the same plates were heated again, to a little further extension of the discoloration, and placed on the hearth-stone to cool;—the powers, as in the other cases, before and after testing, being once more determined on the trial-board. The whole of the results are comprised in the annexed table:

No. of the Plate.	Weight in Grains	Original tempered state. Temper T.		Reduced in the middle and quenched.		Reduced again and cooled gradually.	
		Maximum Power.	After the Test Bar.	Maximum Power.	After the Test Bar.	Maximum Power.	After the Test Bar.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		° ′	° ′	° ′	° ′		
I.	634	19·8	5·24	18·41	5·7		
II.	246	13·54	5·15	13·45	4·46	13·47	4·29
III.	162	10·39	4·29	10·45	4·10	10·44	3·55
IV.	147	10·8	— 1·0	10·10	— 1·4	9·56	— 1·13
V.	120	10·0	+0·42	10·10	+ 0·7		

These results completely verify, I think, the views just suggested, by which an apparent difficulty becomes not only accordant with, but confirmatory of, the general laws. For here, it will be perceived, by comparing columns III. and V., that, in three instances out of five (numbers III. IV. and V.), the reduction in the temper of the plates yielded a small augmentation of the magnetic energy—in accordance with the fact in the particular case inquired into. But this augmentation, it is observable, belongs *to capacity only*, and not to strength or tenaciousness. For the effect of the test-bar (constituting a more severe trial of the "strength" for retaining magnetism than that yielded by the combination of the 8·7-inch plates in one fasciculus), was uniformly to shew a deterioration in tenaciousness. Comparing columns VI. and VIII. with column IV. (the latter shewing the power of the respective plates under the action of the test-bar in their original condition, as to temper), we find an undeviating verification of the previously held law,—viz. that, whilst a reduction of hardness may, within certain limits as to mass, yield increase of energy, it is obtained at the expense of a measure of tenaciousness. The gain, therefore, in the combination of the 8·7-inch plates, by a slight reduction of their temper in the middle, appears to be due simply to the increase of capacity for magnetism yielded to the plates by this change,—a gain, however, which, it now appears evident, would have disappeared, had the plates been subjected to a sufficiently high degree of violence.

That this is no arbitrary assumption, we may assure ourselves by comparing the *proportional* advantage in the reduced temper (table, page

137) at the beginning and end of the series. In the first instance the increase of power in the plates *separately*, by the partial heating in the middle, was about one-fifth of that of the plates in their original and equable temper; but the *proportionate* gain, when the twenty-four were combined, had reduced to about one-tenth. So that, had the combination been carried sufficiently far, the set of plates which had been improved by being partially heated, would, in all probability, have been ultimately found inferior to those in the original state.

Having projected the powers of this series of plates in their different alterations of temper, after the manner of the diagrams already given, I found this result, apparently, inevitable;—for the production of the curves, so far as obtained, in a regular form, caused them to intersect at the place of about the thirty-second plate, and to yield, ultimately, (in exact accordance with theory) an unequivocal indication of superiority of power to the harder or original condition of the plates. [See Diagram, No. 4.]

Guided by this view of the once perplexing difficulty, the explanation of the differences in the results of the other experiments connected with the same inquiry, becomes, for the most part, abundantly simple. For it would hence appear, that the *loss* of power in the thin two-feet plates, by their being reduced in the middle (table, page 139), is to be attributed to the over-reduction of temper—of the effect of which, in an extreme case, we have a striking example in the thorough softening of the 8·7-inch plates, described at page 145. In the case of the larger series of two-feet plates, in which the powers of those equally tempered, and those "softer in the middle," are compared (table, page 142), we infer a like condition, in explanation of the fact of a loss of power in the plates of reduced temper, viz., that they were softer in the middle than was consistent with the modification of structure resulting in gain of capacity.

In regard to the particular instances given in the last table, in which the reduction of the temper of two of the plates, *though very slight*, was attended with a loss, instead of a gain, in the resulting energy, other circumstances, relating to the quality of the steel, degree of hardness, or the original *mode* of tempering, might perhaps, if fully known, have explained the difference in the results. But these inequalities are of no consequence in the more immediate inquiry; our object being to shew, as I trust has been accomplished, that the *apparent discrepancy* of the results obtained by slightly reducing the temper of the series of 8·7-inch plates—as to their power in combination—does not militate against the laws previously determined, nor does it invalidate the principle of the mode of *testing* for ascertaining the degree of hardness.

At all events, the embarrassment occasioned by this particular case, in its bearing upon certain principles deduced from the former investigations, has been fairly and candidly stated, and the series of experiments connected with it given in detail. The scientific reader, therefore, will be able to form his own judgment on the explanation just suggested—whilst the magnetician may be induced, perhaps, to investigate the case more fully, so as to come to a still more decided conclusion in respect to the exact conditions on which all the apparent differences depend.

2. *Of the magnetical powers, separately, and in combination, of steel plates variously tempered, both in extent of surface and in degree of hardness.*

The object of this investigation was to determine, not only the effects of various differences in the degree of hardness, in similar plates, and of inequalities of temper in the same plates, upon their respective magnetic capacities and tenaciousness; but also the relative effects of such differences of temper on *combinations* of plates similarly prepared, as compared with the effects on *single* or separate plates.

Well calculated for the proposed inquiries was a series of steel plates, of the nature of busks used in the stays of females, tempered, in sets, in a considerable variety of ways, which had been considerately prepared for me by Mr. Davenport of Sheffield,—a manufacturer whom I had employed for the construction of a considerable part of the bars and plates used in the foregoing investigations.

The whole series comprised twenty-one plates of steel of similar dimensions, very nearly,—the length of each being 14·4 inches; the breadth 1·5 inch; the thickness about ·025 inch. They were correspondingly tempered in sets of *three* plates, and comprised the following varieties, in the description of which the average weight of the plates of each set is specified:

No.		Average Weight. lb.
I.	The steel in the three plates of this set was described as being in the "raw state," as it comes from the rolling-mill, *quite soft* -	·140
II.	The same kind of steel, *hardened throughout,* as hard as glass - - - - - -	·138
III.	Similar busks *tempered,* spring temper, in *the middle,* the ends remaining quite hard -	·133
IV.	Similar busks, *tempered at one end,* the rest quite hard - - - - - - -	·137
V.	Similar busks, *tempered at both* ends, the middle quite hard - - - - -	·133
VI.	Similar busks, tempered throughout, and quite elastic - - - - - - - -	·139
	[All the above were black and unpolished.]	
VII.	Three busks, quite finished, tempered, glazed, perfectly elastic, select specimens - -	·132

With these busks—being all magnetised carefully by process KS—experiments, separately and variously combined, of which the following table contains the results, were made:

TABLE of Comparative Powers of Seven Sets of Magnetized Steel Busks, tempered in different ways, and subjected to different extents of combination.

[Deviations at Two Lengths from the Compass.]

Sets of Three Busks.	Mean Power of each Busk.	Tangent.	Sum of Tangents of the 3 Busks.	Three Busks in combination, [Mean of two experiments.]			After the whole twenty-one had been in combination; two experiments.			State of separate Busks after combination.		
				Deviating Power.	Tangent.	Loss per Cent.	Deviating Power of the set.	Tangent.	Loss per cent. in the 3.	Mean Power.	Tangent	Loss per Cent.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
	° ′			° ′			° ′			° ′		
I.	5·37	98·3	295	11·25	202	33·5	—2·32	—44	113·0	—1·0	—17·5	118·0
II.	4·7	72·0	216	11·16	199	8·0	+10·40	+188	13·0	+3·43	+65·0	9·7
III.	4·44	82·8	248	12·59	231	6·8	9·36	169	31·8	3·26	60·0	27·5
IV.	4·35	80·2	241	11·23	201	16·2	8·47	155	35·6	3·6	54·2	32·4
V.	4·40	81·6	244	10·43	189	22·6	6·49	120	50·8	2·28	43·1	47·2
VI.	6·39	116·6	350	15·6	270	22·8	2 30	44	87·4	1·21	23·6	79·8
VII.	6·15	109·5	329	14 33	260	21·0	8·55	157	52·3	3·29	60·9	44·4

The relative measure of retentiveness, or strength, in the different combinations, especially under that of the greatest violence when the whole series was laid together, we have here very strikingly and satisfactorily exhibited. For we have here proved, what theory suggested, that whereas the perfectly hard plates received the weakest power, in their separate condition after being first magnetised, yet these were found to be the most energetic after the whole series had been placed in a mass.

The comparative capacity for magnetism, separately, of the different classes of busks, is shewn by the angle of deviation, column II., or by the numerical tangent, col. III., and the sum of the powers of the three busks of each set, by the tangent in col. IV. Comparing col. IV. with col. VI.—the tangent of the deviation produced by the three busks of each set, laid upon each other and pressed together by a weight of about a pound—we obtain the proportional loss by this measure of combination, which is represented in col. VII. And comparing col. IV. with col. IX.—the tangent of the angle of deviation produced by each set in combination, after they had been laid in one mass, and the several busks of each set dispersed in an alternating series in the mass, and the whole compressed together by tying—we find the proportional loss produced by this exposure to the greater violence, represented in the ratio per centum in col. x. Comparing, finally, col. III. with col. XII.—the tangent of the average deviation of the three busks of each set, tried separately, after the combination of the whole mass—we perceive the proportional loss in the busks, severally, by this combination, represented in col. XIII. at the rate per centum.

The influence of tempering, or the reduction of hardness, in producing a diminution of *strength* in the busks—was evinced in the case of the series No. IV., tempered only at one end, in a manner much more strikingly than appears in the table. When first magnetised and tried separately, the average power with the *hard* extremity presented to the compass, was 4° 35′, and with the *tempered* extremity the same: combined in their own series of three busks, the hard end exhibited a deviating power on the compass of 11° 38′—the tempered end of 11° 6′. After combination in the whole mass, the three busks together produced a deviation of 10° 0′ with the hard ends towards the compass, and of 7° 53′ with the tempered ends towards the compass,—the average power of the three busks separately now being—hard end towards the compass 3° 45′—tempered end 2° 27′.

In series No. I.—in which the busks were perfectly soft—the magnetism was not merely neutralised by the effect of the violence of the mass, but the poles reversed. And in series No. VI.—tempered throughout, the power was almost destroyed. The great difference betwixt the effect of the violence on sets No. VI. and No. VII., is only to be ascribed to temper, which, though *supposed* by the manufacturer to be the same, was, no doubt, very dissimilar.

No account has been taken in these, or in any of the foregoing, experiments, with similar plates, of the little differences of weight in the several plates,—because of the small corrections which might be requisite for reducing the observations to uniformity of mass in each plate, being much less than the differences arising from want of correspondence in the nature of the contact, in the process of magnetising the plates, or from varieties in the actual condition of corresponding series, as to temper, or density of the substance.

The total energy of the mass of twenty-one plates in combination, when bound together by a string, was found, in one experiment, to be equivalent to a deviating influence of 26° 53′; and, in another, after the whole of the busks had been remagnetised, of 26° 50′. But had set No. I. been withdrawn, which had abstracted from the total power, and also No. VI., the effect of which was doubtful—the deviating power of the remaining fifteen harder busks, would, without doubt, have proved much greater.

3. *Of the magnetic powers of combinations of* very hard *plates and bars.*

Finding, from the various investigations on the hardening of steel, that the condition of hardness was so advantageous to magnetic energy when tried both on single bars of considerable thickness, and on plates combined into moderate masses—it became important to determine—what positive measure of advantage the *greatest hardness* might yield, when the steel so prepared should be subjected to the violence of still more powerful magnetic combinations?

(1). *As to hard plates.*—In the trial of the busks, employed in the experiments detailed in the preceding section, it was found, that, although the capacity of the hard busks (No. II.) for the magnetic condition, was the lowest of the series when taken separately, yet when compared with others as combined only in sets of three, their united powers had gained an equality, nearly, with several of the other sets. When it was also found, that, subjected to the violence of a combination of all the different sets together, the hardest plates had advanced beyond the power of any of the others;—it became quite obvious, that a much greater *ultimate* power might be obtained *in combination*, by the employment of thoroughly hard plates, than by any of the combinations of tempered plates hitherto employed.

For the determination of the real effect of such combination, as to its comparative advantage, a large quantity of busks, thoroughly and similarly hardened, was ordered of the manufacturer. These consisted, in the first instance, of 72 similar plates—but the number was afterwards increased to 192. The common or average dimensions of the whole, were, 15 inches in length, 1·5 inches in breadth, and ·025 inch in thickness; and the average weight was ·1534 lb. or 1074 grains. They were all in a rough state, just as the plates came out of the bath in which they were hardened.

The separate action of these plates on the compass, at two lengths' distance, was such as to produce a mean deviation of 3° 21′.

The following table exhibits a twofold series of experiments: first, of the powers of 72 plates; and, secondly, of those of 192 plates. In the first series, the powers in combination of 12 plates are given in a regular series, and then the effects of further additions of two, six, or twelve plates, to the fasciculus, up to the amount of 72. In the second series, the powers are given in successive additions of 24 plates after the first 12. The plates, on this occasion, were tied up in bundles of a dozen, and the accession of magnetic power was observed on every addition of two such bundles.

Series of 72 hard Plates.						Series of 192.		
No. of Plts.	Mean Power.		No. of Plts.	Mean Power.		No. of Plts.	Mean Power.	
	Deviation.	Tangent.		Deviation.	Tangent.		Deviation.	Tangent.
	° ′			° ′			° ′	
1	3·18	58	14	32·25	635	12	26·42	503
2	6·23	112	16	35·5	702	24	41·8	873
3	9·41	171	18	37·15	760	48	54·14	1388
4	12·10	216	20	39 15	817	72	60·16	1751
5	14·38	261	22	41·15	877	96	63·20	1991
6	17·15	311	24	42·38	921	120	66·0	2246
7	19 22	352	30	47·2	1074	144	68.32	2543
8	21·40	397	36	50·52	1229	158	70·21	2801
9	23·50	442	42	53·17	1341	192	72·6	3096
10	25·37	479	48	55·30	1455			
11	27·50	528	60	58·32	1634			
12	29·17	561*	72	61·19	1828			

* The first 12 plates of the series of 72 were combined under a pressure only of 2 pounds, the remainder under a 3-pound pressure. The plates, however, being uneven, were far from being in general contact. When the 48 plates, producing a deviation of 55° 30′, were compressed, by being tied tightly with twine, the deviation fell to 53° 15′; but they recovered their power, when restored to their former state of pressure, to the extent indicated by the deviation, 54° 38′.

It has been shewn, in the Results of the investigations on the powers of combinations of magnetised plates of *tempered* steel, in contact, (Part II. chap. I.), that such combinations, if numerous, soon cease to be very effective; so that no extent of additions would more than double the power of the first six plates of the kind there referred to. But here, in the use of hard plates, we have a remarkable and satisfactory improvement; for we find the power of the first six plates actually doubled by 14, trebled by 24, quadrupled by 36; whilst the power of 192 plates is nearly ten times as great as that of six!

Comparing, again, the powers of these hard plates, in combination, with those of bars, tempered as they usually are in the manufacture of magnets in this country, we find equally remarkable and satisfactory results.

Not to take the case of magnets of different lengths, where the comparison becomes less conclusive, I shall here only adduce the proportions of the powers of a set of bars, constructed expressly for this comparison, of the same length and breadth as these dimensions of the hard steel plates.

These bars were made of "blister steel," and consisted of one pair of the thickness of 0·28 inch, weighing 1·762 pounds each; and of another pair of the thickness of 0·47 inch, weighing, on an average, 3·006 pounds. These thinner bars were each equal in mass to a little more than eleven of the hard plates; and the thicker to about twenty.

In the first comparison, the bars were only tempered at a blue, in a very short extent at the ends, (the whole of the intermediate portions being soft,) and in that state the power of the *thin* bars, separately, was to that of an equal mass of hard plates, as 1 to 2·64. But the thick bars, being of inferior quality, not having undergone the same hammering (see p. 84), had only a magnetic capability, compared with that of an equal mass of hard plates, in the proportion of 187 to 817, or as 1 to 4·4 nearly. The power of the two thinner bars together, compared with a corresponding weight of hard plates, was as 1 to 3·9: and of the two thick bars as 1 to 6·0.

The bars were then made *hard* at the ends (without being reduced or tempered) for an extent of about three inches, when their magnetic capabilities were found to have improved; so that each thin bar, compared with a like weight of hard plates, now exhibited the ratio of 1 to 2; and each thick bar of 1 to 3·4. Tried in combination, the ratio of power of the pair of thin bars, with an equal mass of hard plates, was as 1 to 2·7; and of the pair of thick bars, as 1 to 4·5.

In the next comparison, the hardness of the ends of the bars was reduced to a blue temper, when the comparison, with equal masses of hard plates, gave the following ratios:—Each thin bar, as 1 to 2·3; the pair of thin bars, as 1 to 3·2. Each thick bar, as 1 to 3·6; and the pair of thick bars, as 1 to 4·7.

For a final comparison, the bars were ordered to be made as hard as possible; but this order was only accomplished with the thinner pair—

all the efforts of a clever artisan having failed to harden the others. The result with the thinner bars, however, was satisfactory—each bar exhibiting a much nearer advance towards the powers of the hard plates; the proportion of equal masses now being as 1 to 1·46, with one bar, and as 1 to 1·62, with the two bars combined.

We thus find the superiority of the magnetic powers of combinations of hard plates, over those of bars tempered or hardened in different degrees, to be most decisive. Whilst the power of these *hard* plates, individually, was (in accordance with former experiments and with theory) found to be *inferior* to that of *tempered* plates; that inferiority, it is obvious, only belongs to a very limited mass. For inasmuch as the deterioration of the hard plates, by the violence of combination, is so much less considerable than it is in softer or tempered plates or bars,—the proportional power in the hard plates, as so combined, rapidly gains upon that of combinations of *tempered* steel, so as, after a series, perhaps, of six plates, to come to an equality of power with the best capacities of steel of any other temper. Beyond that proportion of combination, the comparison becomes wholly in favour of the hard plates, and goes on, in an improving ratio, to the utmost extent to which addition to the combination can be usefully made.

The diagram No. 3, Plate III., will satisfactorily represent to the eye, the comparative powers of combinations of hard steel plates, and those of single bars, or pairs of bars, as tempered at the ends only, in the ordinary manner of magnets, and also as hardened throughout. The dotted portions of the curves are only inferential; but they are abundantly borne out, as proximate powers, by analogy with the curves yielded by the powers of large combinations of bars of other dimensions.

The series of successive powers, it may be observed, exhibited by combinations of hard plates (as given in the preceding table), is not quite so regular as that heretofore obtained from combinations of *tempered* plates, and this for one very obvious reason: the imperfect and irregular nature of the contact obtained in these unavoidably uneven plates. Besides this inequality in the measure of contact in the smaller bundles of plates,—a similar condition was inseparable from the various combinations of the different bundles; so that when, at certain limits, the whole were strapped together, the increase of pressure necessarily occasioned a diminution in the power of the whole fasciculus, and a consequent inequality in the series. After the last result had been obtained, the whole mass, of 192 plates, was formed into a square prism of equal sides: the magnetism, then, being more condensed, the power was considerably reduced. So also, some of the other combinations, when unduly pressed together, were reduced beneath the general average.

From this diagram—in which the abscisses are on a scale of just five-ninths of those of diagram No. 2, and the ordinates of one-third—we may readily perceive the amazing advantage, in large combinations, of the magnetic capabilities of hard plates, over plates or bars otherwise tempered. The ultimate gain of the hard plates, over a combination of bars of 0·28 inch thick, tempered along a considerable extent at the ends, appears, by the proximate curve, to be in the ratio of nearly seven to one; or compared with a series of similar bars, tempered in the manner in which compound magnets are usually prepared in this country, the ratio would be still higher. And comparing these powers of the hard plates, with the power of the same bars when hardened in a like manner, as far as the steel was susceptible of hardness, we find (by reference to the middle curve) that the fasciculus of plates still has the advantage in the proportion of, probably, nearly two to one. Had, however, the combination of hard plates been carried farther, it is quite obvious, from the mere inspection of the diagram, that the differences, in their favour, would have been increasingly conspicuous; for whilst the bars of the ordinary kind of temper had long ceased to gain anything worth notice, by additions of like bars to the mass,—as shewn by the horizontality of the extension of the lower curves—the curve, expressive of the power of the hard plates, is still found to rise at a considerable angle with respect to the direction of the line of abscisses.

It has been remarked, that the proximate part of the curves (distinguished by dotted lines) has the support of analogy derived from actual experiments with some large series of bars and plates of other dimensions: so that the direction and elevation of the lower curve especially, cannot, I think, be far from the truth. The *probable* accuracy, however, it is to be observed, only relates to results with corresponding, or medium, qualities of steel; for it should be borne in mind, that the statement often made—"that the magnetic qualities of different denominations of steel, if of ordinary goodness, are not essentially various"—is most fallacious, as *very great differences* will be found, as before shewn, in the magnetic powers of the several descriptions and qualities of steel. Hence, none of the curves of these diagrams, if applied *generally* are to be considered otherwise than proximate, as to their elevation, or as to the measures of their ordinates.

As to the diagram No. 3, the curve, representing the powers of hard plates, has been derived from experiment with steel of ordinary quality, so that, were the best cast-steel substituted for a similar experiment, a very large increase would doubtless be given to the elevation of the curve.

(2). *As to hard* bars *in combination.*—The great gain in magnetic power obtained by the use of hard *plates*, rendered it quite certain that a gain, somewhat similar, would result from the thorough hardening of the *bars* designed for magnetic combinations. The measure of gain, however, was matter of experiment.

A set of bars well adapted for such experiment was that repeatedly referred to in chapter I., of this part of these Investigations, consisting of a series of similar bars, ten in number, 13·8 inches in length; 1·1 inch in breadth, and 0·255 in thickness. The average weight of these bars was 7462 grains, and the total weight of the ten, 10·66 pounds.

They were orginally made for a pair of compound straight-bar magnets, five bars in each, and tempered in the usual manner at the ends only. Their powers were always moderate; and the apparatus, which they formed, was found soon to lose much of its energy. Having carefully magnetised the whole set, determined their separate powers, tested their respective qualities, and tried their powers in combination, on every addition of bar by bar to the mass, up to the completion of the series,—I then sent them to a manufacturer in steel, at Sheffield, to be thoroughly hardened.

On their return, though the hardness of the bars was neither complete, nor equable; yet a most decided and satisfactory improvement was found to have taken place in their magnetical capabilities. The comparison of their respective powers in the two conditions, as to hardness, will be the best exhibited in a tabular form:

TABLE of the Magnetical Powers (Maximum Capacity and Tenaciousness) of a Set of Ten Bars of 13·8 Inches in length, in Two States of Hardness.

[The distance from the Compass was Two Lengths, or 27·6 Inches.]

Nos. on the Bars.	Weight in Grains.	I.—Bars tempered only at the Ends.				II. The same hardened throughout at a low red heat.			
		Highest Deviation separately.	Deviation when *reduced* by combining 5 Bars.	Powers in Combination.		Highest Powers separately.	*Reduced* by Combination of 10 Bars.	Powers in Combination.	
				Mean.	Tangent.			Mean.	Tangent.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
		° ′	° ′	° ′		° ′	° ′	° ′	
III.	7575	17·10	12·12	17·10	309	18·5	12·20	18·5	327
VIII.	7480	16·0	11·0	20·0	364	19·8	12·4	30·5	579
X.	7330	15·5	10·5	21·10	387	19·5	14·47	36·20	735
VII.	7500	15·20	9·35	22·55	423	19·56	14·40	41·50	895
V.	7270	16·40	8·30	25·30	480	19·12	13·34	44·40	988
I.	7500	15·55	8·5	28·30	543	18·20	13·44	47·7	1077
IV.	7550	15·50	8·0	30·10	581	18·0	5·45	[omitted.]	[omitted.]
II.	7300	15·30	6.55	31·30	613	18·20	14·23	49·55	1188
IX.	7510	12·20	1·10	30·0	577	17·30	8·33	51·20	1250
VI.	7610	11·0	0·50	28·45	549	14·22	—2·40	[49·10]	[1157]

The effect of hardening this set of bars, was thus shewn to be in exact correspondence with what had been anticipated. Comparing columns III. and VII., we perceive the general gain of magnetic capacity, by hardening, in the bars individually; and comparing columns VI. and X., we see the still further gain obtained under the respective combinations, bar by bar, up to the amount of the whole series.

A similar experiment was made with the bars of a large compound magnet of the horse-shoe form, and with an analogous result. These bars were nine in number, and had been moderately hardened, in the usual way, only at the ends or poles. They were composed of the ordinary quality of steel, and weighed, on an average, 2·56 pounds, or, in the whole, 23·05 pounds. In the original state of the instrument they had a lifting power, separately, when most highly magnetised, of about 14·3 pounds; but this power, after the conductor had been once removed, fell to that of 8·9 pounds.

As it would have been a very difficult task to have hardened these bars throughout, without change of form—I got them hardened, at a bright red heat, in all parts except at the bend, which, being left soft, enabled the artisan to adjust them, pretty nearly, to their original shape.

With this measure of hardening, an improvement, fully as great as what I had anticipated, was found to have taken place in their magnetical properties. Their separate lifting powers, indeed, *before* the removal of the conductors which had been attached to them, severally, during the magnetising process, was not greatly augmented—the amount of their powers, as tried separately, having only increased from 124 to 134 pounds. But *after* the removal of the conductors, the comparison of their subsequent powers indicated an improvement in the proportion of the advance from 80 pounds to 120 pounds,—the former being the amount of their separate lifting powers after the removal of the conductors in their *original* state, as to tempering; and the latter in their *hardened* condition.

When the power of the whole series of bars was tried in combination—an equally satisfactory improvement was determined. In the original state of the complete magnet,—after being highly magnetised, and carefully put up whilst each bar was defended by its own conductor, and these separate conductors gradually displaced by sliding on the large conductor of the entire instrument,—the power sustained by it was gradually increased to 70 pounds before the conductor was pulled off: but, on a second trial, the lifting power was found to have fallen to about 30 pounds. Now, however, after the change in its degree of hardness, it was found to sustain (under the great disadvantage of an uneven surface where the conductor was applied) considerably above 80 pounds; and after the conductor had been separated, several different times, it still readily sustained 80 pounds, or upward!

Hence, the very manifest improvement of the instrument. First, a considerable increase in its sustaining power before the removal of the conductor; and, secondly, an improved degree of permanency of power, such as that indicated by a comparison of the powers in the two different states, when once the conductor had been removed. In the original state, the sustaining power fell, on the removal of the conductor, from 70 to about 30 pounds; in the improved state, the power only fell from, perhaps, about 85 to 80 pounds, or scarcely so much!

Finally, under this head of Investigations, I may mention the effect of hardening on the series of 8·7 inch plates—which had been subjected to such a variety of treatment in tempering—for the purpose of following out the inquiries in section I. of this series. I took eight of those which had been thoroughly softened in the fire (p. 144), and annealed them at a bright red heat, in cold water. They were found to be extremely hard, and as brittle as glass. Their magnetic capacity, separately, was now reduced from a deviating power (at two lengths from the compass) of near 10°, in their original state, at a spring temper, to about 8°. But their power in combination had proportionally increased—the eight plates now exhibiting a power of 30° 30′, whereas twenty-four plates, in the original state, as to temper, only had a power of 28° 41′.

In the diagram No. 4, the powers of these eight hard plates are represented, and carried forward by the continuance of the curve, to the probable result of the whole of the original series of twenty-four. The lowest curve in the diagram represents (as projected in like manner) the powers of the same plates when thoroughly softened.

RESULTS.

Of the General Results of the foregoing Investigations on the powers of magnetised steel plates or bars, *as affected by differences in the degree of hardness*, or nature of temper,—I proceed to select a summary. But in order to the extension of results, having a most important bearing, practically, on one of the leading objects of this work—the improvement of magnetical apparatus—I shall here avail myself of certain important facts (being in strict conformity, in analogy, as to the effects of temper) elsewhere derived, and especially of those elicited by the Investigations in Part I., as exhibited to the eye in the diagram in Plate II.

1. That the relative powers of *combinations* of magnetised plates or bars of steel, as well as those of single pieces,—are greatly affected by differences in the state of the steel, both as to its quality and as to its temper.

By the *powers* of magnets is to be understood, not the capacity for magnetism, as indicated by the force required, in the first instance, to remove the conductor by which, during the magnetising process, the magnetic arrangement had been sustained, but the magnetic energy which remains in a bar when detached from the conductor, or other sustaining magnets.

The effects of the *quality* and *denomination* of steel, on its magnetic properties, have, to a certain extent, been shewn in Part I. chap. VII., and the particular cases noticed at pages 46 and 84.

The general effect of *quality* becomes more and more important, as the mass, or combination employed, is enlarged. Hence, *inferior* qualities of steel, however energetic small magnets, constructed out of them, may appear, are incapable of very extensive combinations with advantage, or of being usefully employed, as magnets, in large and heavy bars.

Hardness of the steel operates in a similar manner as *quality* on the magnetic properties of large masses; so that increase of hardness greatly improves the capacity for *sustaining* the magnetical arrangement or condition, where, on account of the size, the tension is great.

2. That various degrees of hardness have an influence on the magnetic capacity and energy of steel, differing, both in the *nature* and *quantity*, or proportion, with the magnitude of the masses employed; so that that kind of tempering, or degree of hardness, which may exhibit superiority with a certain mass, may be found greatly inferior in other magnitudes.

This result will be very apparent, if we merely inspect the relation of the curves in either of the diagrams, No. 1, or No. 3. The first diagram shews, very strikingly, the change which takes place in the relative powers, as to directive energy, in magnets of different degrees of hardness. Thus comparing the effects of the four distinctive kinds of temper there indicated, on the magnetic capabilities of very thin plates; such as, for instance, on single plates of 6 inches long, and of the weight only of 100 grains,—we find, that the order of energy, commencing with that of the highest, is in favour of—1st. Tempering at the ends; 2d, tempering throughout; 3d, being left soft; and 4th, being made quite hard; or, to use the distinguishing letters there employed, in the order E. T. S. H.—Comparing, next, the powers of plates of 200 grains weight, the order is found to be changed to T. E. H. S.—Comparing again the powers of plates of 300 grains, we have the order T. H. E. S. —And comparing, finally, the powers of the same sets of bars in masses of 400 grains, we have the order, never afterwards altered, except as to quantity, or proportions, H. T. E. S.

Analogous results, as to the respective powers of *cast steel* bars or plates of different degrees of hardness, are derived from the inspection of diagrams Nos. 3 and 4, and also from the experiments with busks of various degrees of hardness described in section II. of this chapter.—But more particular reference to these cases is reserved for the illustration of the next proposition in these Results.

With regard to the *proportions* of the magnetic powers of bars of cast steel, or combinations of cast steel plates, of different degrees of hardness, we find a change with every alteration in the masses compared. Thus, with reference to the comparative powers of magnetised steel bars, as exhibited in the first diagram, we find the ratio, unequated, of the series of bars No. I. (of about 3000 grains weight) to be 100, 76·6, 58·3, and 40·9, in the order of the several degrees of hardness H. T. E. S.;

whilst the ratio of the corresponding series of bars No. II. (being about 1400 grains weight) appears to be—100, 79, 67, 49; and the ratio of series No. III. (of about 700 grains)—100, 87, 75, 56, nearly.

These proportions, as well as the places in the line of abscissæ at which the different curves cross each other, are only proximate. For in case of the degree of hardness of any of the sets being different, some alterations would be made both as to the proportions of the powers of the different descriptions of bars, and as to the places of the intersection of the curves.

3. That the pre-eminence of *partially tempered* or *slightly hardened* straight-bar magnets, for the magnetic condition, belongs only to very limited masses,—whilst in fixidity, or permanency of power, the softer magnets are always inferior.

The first part only of this proposition needs to be illustrated here—the second belonging more particularly to the investigations of a subsequent chapter.

It has just been shewn that, however in certain small masses a *moderate degree of hardness* may have an advantage in the first instance, as to magnetic energy,—on the comparison of bars of six inches in length, and half an inch in breadth, it was found, that this occasional pre-eminence in any inferior measure of hardness gives place to the condition of the greatest hardness, in the particular case investigated, whenever the weight of the bar (being of best cast steel) exceeds 400 grains, or the thickness one-fifteenth of an inch.

In the case of the experiments described in section II. with the variously tempered busks of fifteen inches in length, analogous results were obtained.

Comparing these plates, as to their relative magnetic powers, *singly*, we find (table at page 155) that the most energetic were those of a spring temper throughout—Nos. VI. and VII.; next in energy were those in the soft, or "raw state," No. I.; and the feeblest were the very hard set, No. II. But when three of each kind were combined together, the hard busks, which, individually, had only two-thirds as much energy as those that were of an elastic temper, had now *more* than three-fourths of the power of these; whilst they had already advanced beyond, or nearly to equality with, several of the other kinds.

Carrying the comparison still further, which other experiments not herein detailed enable me to do, it was found that, after a combination of about eight plates only, or a total thickness of cast steel of about the fifth of an inch, the thoroughly hard busks had an universal pre-eminence.

In the comparison of *bars* in combination, in sets of different degrees of hardness—a similar limit to the superiority of those moderately hardened, as to the first energy received, was experimentally determined. In the case of the two-feet bars described at page 101, the powers of which were determined in three states of hardness—there was found a progressive increase in correspondence with the increase of hardness; and in the case of the sets of 13·8 inch bars and of those of the large horse-shoe magnet, referred to in the last section of this chapter,—each bar, separately, gained somewhat in energy by being hardened, and when tried in combination exhibited a large accession to their original power, as tempered in the ordinary manner.

In diagram No. 2, the powers of perfectly hard plates of cast steel, are compared with those tempered like cutlery throughout. At the 12th plate the inferiority of the hard plates disappears; and beyond that number they assume their usual pre-eminence over those of less hardness when in similar contact.

4. That, in combinations to a small extent of magnetic power, a moderate degree of hardening throughout will yield effective or superior energy; and that measure of energy will, under certain conditions, be increased by slightly heating or reducing the middle of the thoroughly tempered plates.

This proposition, as to the first part of it, has already had abundant verification. The second part of it, which is analogous to a conclusion arrived at by Captain Kater, is derived from the experiments detailed in the first section of this chapter, where the measure of the apparent reduction, and the proportion of gain in magnetical capacity, have been already considered.

The advantage yielded, however, by this slight reduction in hardness, to the immediate magnetic energy of the particular set of plates referred to at pages 134 to 138, was found, as the extent of combination advanced, to become proportionally less and less considerable. The case, indeed, as determined by Captain Kater, was limited to that of thin plates, employed separately as compass needles; and here the same result is found to be correct in combinations of plates to a very considerable extent in number, the energy being but moderate.

This circumstance, as has been shewn in the text of the foregoing chapter, occasioned me, at first, much embarrassment, as being, apparently, at variance with the law so extensively verified respecting the general advantage of hardness for magnetic power in large combinations of steel plates or bars. But, after a variety of investigations for the solution of the apparent discrepancy, it was found to be resolvable into the general law, the difficulty having arisen from want of regard to the actual weakness of the combination. Though the plates were so numerous (being twenty-four in number), yet they were so little energetic in combination that the whole series did not double the power of the first two,—the total energy, indeed, not exceeding what might be obtained in a single hard plate of shear steel, or tempered plate of cast steel of, perhaps, 1500 to 1800 grains weight.

Had, therefore, the combination been carried to a high degree of energy, it is obvious that the powers of the harder series would have become superior. For the harder series was found so to gain upon those that were reduced, as the mass increased, that it would have come, no doubt, to an equality, if the number of plates had been augmented to thirty-two, and beyond that number would have obtained the pre-eminence. See diagram, No. 4.

5. That whilst the order of superiority in magnetic plates or bars of *like* form and length, but of *different* degrees or measures of hardness, varies, within certain limits, as the mass is diminished or enlarged; yet, the limits of the degrees of hardness which are the most effective for *all practical uses,* may be considered as comprised betwixt a brittle hardness, like that of files, and that of an elastic or spring temper.

The relation to each other of the various curves in diagram No. 1. (plate 11), as they appear near their commencement, may be appealed to as sufficient to support the truth of this statement as a general practical proposition. For herein it plainly appears, that, as to all essential or material advantages, in any particular kind of tempering or degree of hardness—the choice mainly rests between the degrees of hardness indicated by the curves T and H, or the intermediate modifications.

As to the case of plates or bars perfectly soft (S), we find that this condition is unequivocally inferior; and as to the case of plates or bars tempered only at the ends (E), that the superiority in very thin plates which, within small limits as to mass, it appears to possess, is only to a trifling extent;—so trifling indeed, as, when taken in connexion with its disadvantage from the want of fixidity, wholly to set aside this mode of tempering, so generally adopted in the construction of compass needles and other magnetical instruments, as unscientific and bad.

6. That the sustaining property of hardness, on the magnetic arrangement, is such, as to render a considerable extent of hardness generally advantageous, for magnetical apparatus; whilst in very large combinations of straight-bar magnets, or very heavy bars, the greater the hardness the more powerful will be the magnet.

For particular purposes, where a light needle, or plate, may be required—a considerable reduction of the ultimate hardness of which *cast steel* is capable, will be advantageous to its primary energy, and general utility, though the fixidity be not so great. And in magnets of the horse-shoe form, a reduction of *extreme* hardness is generally beneficial. But in all larger masses, in straight-bar magnets, a temper approaching to extreme hardness, becomes in every way the most advantageous condition.

Hence, whatever may be the advantage to the individual magnetic capacity of thin steel plates, by a reduction of hardness; the superior strength or retentiveness of hard plates, eventually causes them greatly to exceed in power, under energetic combinations, those of any other kind of temper.

In the case of the fifteen-inch plates, or busks, very numerously combined, we find that, compared *separately*, the very hard plates had scarcely two-thirds of the power of those of an elastic temper; but when combined to the extent of 192, the hard plates exhibited a degree of energy, probably six or eight times as great as that of which similar plates would be susceptible of a spring temper.—See diagram No. 3.

7. That the most favourable conditions for the construction of magnetic apparatus, by the combination of several bars or plates, require *similarity* of quality and denomination in the steel, a reasonable correspondence in the magnitude or mass of the individual plates or bars, and similarity of temper or hardness.

The first and last of these requisites for making the best use of any series of bars or plates in combination, are proved to be essential by simple inference from the general results of investigations already given, whilst the processes described for testing the quality and hardness enable us very easily to make the proper selections.

The practical methods, in detail, however, will remain to be described in a subsequent part of this work.

The desirableness of the second condition, that of correspondency of mass in the plates or bars combined, may not appear to have been yet determined; though when we consider the impracticability of giving equal degrees of hardness to thick and thin bars, and of equally developing the magnetic energy in thick masses, as we can in thin plates, the requirement may be seen to be one of considerable importance.

The above Results, it should be observed, relate, essentially, to one particular *denomination* of steel—that of *cast steel*—the relative properties of this and various other denominations of steel (both in single bars, and in various combinations, as well as differences of temper), forming the subjects of investigation in the next succeeding chapters. It should be further borne in mind, that the comparative powers, herein treated of, likewise relate, not to all the possible changes producible by every variety of hardness of which steel is susceptible, but, only to such general divisions or species of hardness as have heretofore been designated by the characteristic letters S. E. T. H.

CHAPTER IV.

ON THE RELATIVE POWERS IN COMBINATION, AND SEPARATELY, OF HARD PLATES OR BARS OF STEEL OF DIFFERENT DENOMINATIONS AND QUALITIES.

THAT a striking relation exists betwixt the *quality* of steel, and its magnetical properties, has been shewn, I trust I may say, demonstrated, in chapters VII. and VIII. of the first part of this work. On the other hand it has been shewn, that certain *differences*, probably characteristic, occur in the magnetical powers of steel of different *denominations*—such as "cast," "shear," "double shear," "blister steel," etc., as the several kinds are designated with reference to the manner in which the metal is treated after being "converted"—though the several varieties of steel, as to their denomination in commerce, may have been converted out of the same *quality* of iron.

The experiments, however, heretofore recorded on both these important points, were of too limited a nature to be quite conclusive for the solution of the important problem,—as to the best quality or kind of steel for *all* magnetical purposes, or, rather, for each magnetical purpose specially. For whilst the fact was sufficiently clear, that the *best qualities* of steel have the highest magnetical powers, and, that, for certain magnetical purposes, and powerful magnetical combinations, the best *cast* steel exhibits a decided superiority,—it by no means followed, that *cast* steel as to denomination (not quality), would maintain that relative superiority, in all the different forms, and masses, and degrees of hardness in which the bars or plates of magnetical apparatus might require to be constructed. Nor did it necessarily follow that the results obtained with thick bars, (Part I. chap. vii.)—because of the difficulty of hardening and magnetising them throughout their mass—would, in all cases, be found, especially in proportion of magnetical energy, correspondent with results obtained by combinations of thin plates.

Hence, I thought it needful to institute the additional series of experiments of the class indicated in the title of this and following chapters. And the importance and satisfactoriness of the results amply fulfilled the anticipations I had entertained.

In the series of experiments embraced in this chapter (with the view of special application to the case of compass needles of larger dimensions than 6 inches) I adopted generally the length of 7·5 inches, for the steel plates, with the breadth of 0·75 inch, and a thickness, for the most part, of about 0·08 inch.

The thickness, however, in the several series' designed to be similar, was found, from circumstances which I could not easily control, to vary sometimes more than I could have desired.

One general method of hardening was adopted in the whole of the plates referred to in this chapter; and all the plates, but one set, passed, in their corresponding stages of rolling, forging, grinding, and hardening, through the hands, I believe, of the same artizans. The mode of hardening adopted, was by plunging the plates, when at a bright red heat, into a strong brine. The hardness thus yielded was equivalent to that of files, and was not allowed in any way to be reduced, until the whole of the experiments described in this chapter had been completed.

For the facility of reference and discrimination of the several denominations, qualities, and degrees of hardness of the steel, etc. employed in the investigations comprised in this and the succeeding chapters, the following series of characteristic letters have been adopted.

Characteristic letters of *Denominations* of steel and iron; the *best qualities*, referred to indefinitely, being indicated by the letters in italic capitals.

C.	Cast Steel.
S.	Double Shear Steel.
B.	Blister Steel.
CL.	Cast Steel known to be from hoop-L iron.
CS.	Stubs' Cast Steel.
SS.	Stubs' Double Shear Steel.
I.	Iron.
CI.	Cast Iron.
M.	Steel used at the Mint.

Characteristic letters of the *Qualities* of steel in small (or lower-case) italics.

f.	Steel from a Foreign Iron, not being of the very best, but of a good quality.
fc.	Steel from a common kind of Foreign Iron.
e.	Steel from undescribed kind of English Iron.
b.	Steel from best Bradford Iron.

Characteristic letters, in Roman capitals, as partly employed in the diagram, Plate II., etc., indicative of the temper, or degrees of hardness.

H.	Quite hard; hardened the same way, and to the same extent, as files usually are.
T.	Tempered by being reduced to a blue, or spring temper, equably throughout.
E.	Tempered at a blue, but only at the ends of the bars, the intermediate portions being soft.
S.	Soft; just as received from the rolling-mill or forge.
HT.	Intermediate, betwixt hard and tempered.
TS:	Intermediate, betwixt tempered and soft.
AB.	Annealed in boiling linseed oil.
A.	Annealed in hot oil at some specified temperature.

SECT. I.—*Of the Magnetical Powers, in combination, of Steel Plates (7·5 inches in length), of* DIFFERENT DENOMINATIONS, *but of* THE SAME ORIGINAL QUALITY *of iron.*

Steel of the several denominations of "cast," "shear," and "blister," constituted the chief varieties in the investigations of this section,—the specimens for which were kindly furnished me, for the most part, by Messrs. Stubs, of Warrington, whose tools and files have obtained such just celebrity.

1. Experiments with steel of *different denominations*, converted out of a *peculiar steel (CS)* used by the Messrs. Stubs in the manufacture of files, etc. The basis of this steel is all foreign iron, smelted with wood-charcoal, of the first qualities.

In each case the plates were similarly magnetized by the process K S, upon the large compound magnets of 192 hard plates. The two-feet hard bars were generally found adequate for the development of the highest magnetic condition of which the plates were susceptible; but to secure the maximum energy, without chance of failure, the more powerful magnets were preferred. The deviations produced by the plates, or combinations of plates, were all determined on the trial-board, and at the distance of 15 inches, or two lengths from the compass.

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	III.	IV.	V.
I.—*Cast Steel:* Average Weight, 986 grains. [Tested under a Combination of 36 Plates, or Deviating Power of 71° 47′.]				
	° ′	° ′		° ′
C. H. 1	23·0	23·0	424	14·6
2	18·52	33·32	663	11·0
3	18·42	41·9	874	11·24
4	21·24	47·30	1091	14·0
5	19·20	51·15	1246	9·0
6	20·40	53·44	1364	13·6
Mean	20·20	. . .	371	12·6
II.—*Double Shear:* Average Weight, 890 grains. [Tested under a Deviating Power of 71° 47′.]				
S. H. 1	23·40	23·40	438	3·45
2	23·37	35·20	709	4·27
3	23·30	41·27	883	4·45
4	21·15	44·25	980	6·27
5	21·45	47·20	1085	5·26
6*	22·45	49·0	1150	5·0
Mean	22·45	. . .	419	4·58
III.—*Double Shear:* Average Weight, 630 grains. [Tested under a Combination of 28 Plates, or Deviating Power of 54° 40′.]				
S. H. 1	17·0	17·0	306	4·15
2	16·40	25·0	466	2·28
3	16·30	29·28	565	11·6
4	16·45	31·45	619	5·42
5	16·0	33·46	669	9·32
6	16·53	35·15	707	6·32
Mean	16·38	. . .	299	6·36

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* This is an assumed Plate to make up the Series, five Plates of this kind only being obtained.

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	III.	IV.	V.
IV.—*Rolled Cast Steel:* Weight, 590 grains.				
[Tested under Deviating Power of 54° 40′.]				
C. H. 1	11·12	11·12	198	7·2
2	12·0	19·54	362	6·54
3	11·45	26·52	507	6·0
4	12·0	32·40	641	7·16
5	12·30	36·0	727	8·18
6	12·35	39·0	810	8·42
7	15·0	41·10	874	8·8
8	14·40	44·0	966	9·3
9	15·46	46·0	1036	8·44
10	15·22	47·0	1072	8·40
Mean	13·17	. . .	236	7·53

The "double shear steel" of series III. was supposed, by the persons by whom supplied, not to be highly carbonized. It had been prepared specially for making *springs*, rolled into sheets, and well hammered, when cold, before being hardened.

The "rolled cast steel," series IV., had been prepared for *saw-blades*, and was of a description denominated "very mild."

For the correct comparison of the powers of these four descriptions of steel, an allowance, it will be observed, requires to be made for the differences in weight of the respective series. This may be effected, proximately, by the use of the diagram, Plate II., wherein the powers of plates of 7·5 inches will be represented by those plates of 6 inches, by taking the former in the ratio of the cubes of their lengths, viz. as $7{\cdot}5^3$: $6{\cdot}0^3$, or as 421·875 to 216, or sufficiently near at one-half of their weights.

A correction for the difference of *hardness* is likewise requisite: for it may be perceived, by comparing the loss of power produced in series No. I. by the combination of 36 plates, having a deviating power altogether of 71° 47′, with the loss sustained by series No. II., under the same severity of testing, that the double-shear steel was reduced greatly below the cast steel, indicating a much less degree of hardness. The loss of power in the *shear* steel plates, by the severity of the test to which they were subjected, was, on average, nearly 80 per cent.; whilst the loss sustained by the *cast* steel, under the same severity of trial, was only about 42 per cent. Hence the correction *for weight*, to be added to the mean powers of the plates of set No. II., separately, for a proper comparison with those of No. I., would, in due respect of hardness, be according to the ratio of a curve below that of H, in the diagram, and probably above that marked T. The augmentation betwixt $\frac{890}{2}$, the weight of plates of series No. II. and $\frac{986}{2}$, that of No. I., would in this case amount to 10 on the line of tangents, which being added to 419, the tangent of 22° 45′, or the mean maximum power of the plates of series No. II. separately, would give 429, equivalent to a deviation of 23° 13′.

If to the two series, Nos. III. and IV., the correction for deficiency of weight were applied, with a due regard to their respective curves for hardness, about 80 would have to be added to the tangent of 16° 38′ of No. III., and about 100 to that of tangent 13° 17′ of No. IV.,—giving to No. III., on a mean of the maximum powers of the several plates of the series raised to a correspondence with the weight of No. I., a deviation of 20° 46′, and to No. IV., of about 18° 35′.

The numbers, however, thus obtained are, at the best, but proximate; and where such a variety of circumstances affect the general results, these, within certain limits, must be uncertain. At the same time, some very important practical facts are abundantly developed; but as these will be rendered more conclusive and satisfactory by the experiments yet to be described, they may be with advantage reserved for the summary of propositions after our usual manner, under the title of "Results."

A deduction or two, however, of some importance in the manufactures out of steel, as well as in practical magnetics, may be now noticed. Comparing the power and retentiveness of the plates used in series No. I., with those of No. II., we find, by the much less retentiveness of the latter, (col. V.) that the hardening of *different denominations* of steel in the same way, and at the same heat, produces very different effects, as to the degree of hardness. Thus the process which yields to best cast steel the highest degree of hardness, H; yields to double shear steel of similar quality, a hardness but little superior, apparently, to that marked T. The difference, it would appear, mainly arises from something in the structure of the metal,—the mode of manufacture producing a peculiarity in the arrangement of the ferruginous particles, so as to modify their respective susceptibilities for hardness.

Another deduction, from a comparison of the corrected powers of the series III., of shear steel, with those of the similar denomination, No. II.; as also from a comparison of the cast-steel, No. IV. with No. I., is of some importance for the further verification of the principle of testing. Thus, we find, the mean powers of the plates of each of the four series, when corrected for weight and hardness, to be—No. I. (cast-steel) 20° 20′, and No. IV. (cast-steel) 18° 35′; No. II. (shear-steel) 23° 13′, and No. III. (shear-steel) 20° 46′—shewing an inferiority, in magnetical qualities, of the series III. and IV. Now such inferiority was fully anticipated from the knowledge of the fact of their being in an inferior degree carbonized—a condition designedly given, because of the toughness required in the peculiar purposes for which these two steels were designed—viz. for *springs* and *saws.*

2. Experiments with steel of *different denominations*, converted out of *best Swedish iron*, marked hoop-L.

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	III.	IV.	V.
V.—*Cast Steel:* Average Weight, 952 grains. [Tested under a Deviating Power of 71° 47′.]				
	° ′	° ′		° ′
CL. H. 1	20·33	20·33	375	13·15
2	19·18	33·48	669	11·45
3	19·30	42·18	910	12·0
4	20·40	48·45	1140	13·10
5	20·37	52·44	1314	13·12
6	22·2	55·30	1455	13·13
Mean	20·27	. . .	373	12·46
VI.—*Cast Steel:* (2nd Series of the above) 952 grains.				
CL. H. 7	19·0	19·0	344	11·28
8	19·36	32·35	639	11·30
9	19·45	41·33	886	12·57
10	19·30	47·22	1086	12·22
11	20·15	51·35	1261	12·37
12	19·30	54·20	1393	12·22
Mean	19·36	. . .	356	12·13

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	III.	IV.	V.
VII.—*Blister Steel:* Average Weight, 982 grains. [Tested under a Power of 51° 23′].				
	° ′	° ′		° ′
B. H. 1	22·0	22·0	404	14·16
2	22·50	35·6	703	15·54
3	21·7	41·17	878	14·2
4	21·4	45·27	1016	14·58
5	23·4	49·7	1155	17·30
6	22·34	51·23	1252	17·0
Mean	22·6	. . .	406	15·37

The power, after combination, in this last series, No. VII., being determined under the tension only of six plates, or a deviating power of 51° 23′, whereas the series Nos. V. and VI. were tested under a deviating power of 71° 47′; the last column of No. VII., compared proportionally with the former, will be too high. But the means of a more correct comparison is given in a subsequent summary or abstract of these experiments, aided by the application of an uniform test.

SECT. II.—*Of the Magnetical Powers, in combination and separately, of Steel Plates (7·5 inches in length), of* SIMILAR DENOMINATION, *but of* DIFFERENT QUALITIES *of the original iron.*

By this series of experiments, was intended to be compared, the respective capabilities for the magnetic condition, in various measures of combination, of steel of known but different qualities, in respect of the iron out of which it had been made.

The magnetical capabilities of *cast steel* from Swedish iron, marked *hoop*-L, and also of the *peculiar* cast steel from best qualities of foreign iron, being given in the last section, the results with the additional kinds examined, require only to be here stated.

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	V.	IV.	V.
VIII.—Cast Steel from best *Bradford Iron*: Average Weight, 979 grains. [Tested under a Deviating Power of 49° 45′].				
	° ′	° ′		° ′
Cb. H. 1	28·8	28·8	535	16·30
2	27·55	38·45	803	16·10
3	27·25	43·5	935	13·35
4	27·12	45·10	1006	14·45
5	27·22	47·0	1072	13·5
6	26·43	48·40	1137	15·35
Mean	27·49	. . .	520	14·57
IX.—The above re-hardened: the Numbers not correspondent in each Series. [Tested under a Deviating Power of 50° 0′].				
Cb. H. 1	26·53	26·53	507	15·5
2	27·52	38·55	807	16·32
3	28·5	43·8	937	16·16
4	27·55	46·3	1037	13·52
5	27·40	48·0	1111	16·0
6	28·30	50·0	1192	17·52
Mean	27·49	. . .	526	15·56

No. of the Plates.	Maximum Power Separately.	Power in Combination.		Power after Combination.
		Deviation.	Tangent.	
I.	II.	III.	IV.	V.
X.—Cast Steel from *commonest Foreign Iron:* Average Weight, 943 grains. [Tested at a Deviating Power of 50° 0′].				
	° ′	° ′		° ′
*C cf.*H. 1	23·0	23·0	424	8·10
2	18·55	25·10	470	− 2·20
3	25·28	31·0	601	+ 18·0
4	25·12	34·30	687	16·35
5	17·12	32·0	625	− 6·30
6	25·30	37·15	760	+ 14·45
Mean	22·33	. . .	415	8·7
XI.—The above re-hardened: the Numbers in each Series not certainly correspondent. [Tested as the preceding].				
*C cf.*H. 1	17·10	17·10	309	− 4·0
2	20·32	20·30	374	+ 9·30
3	16·58	22·2	405	− 1·20
4	18·55	25·0	466	+ 3·28
5	20·25	26·50	506	9·10
6	19·12	28·42	547	6·25
Mean	18·52	. . .	342	3·52
XII.—Cast Steel from a *good quality of Foreign Iron,* but not the best: Weight, 1027 grains. [Tested as the preceding].				
C f. H. 1	16·30	16·30	296	11·38
2	18·43	29·5	556	14·52
3	19·37	38·10	786	16·35
4	17·34	43·6	936	12·58
5	17·30	47.18	1083	13·0
6	16·38	49·37	1176	11·46
Mean	17·45	. . .	320	13·28

With these several series of cast-steel plates, converted out of three different qualities of iron, are to be associated the series Nos. I., IV., V., and VI. of the foregoing section. The comparative magnetical qualities, separately and in combination, are referred to in the General Results; but it will scarcely escape observation, on the most hasty glance over the tables, what a remarkable superiority of magnetic capacity, in the *separate* plates, is exhibited in the steel from *Bradford iron.* In plates or bars of the *particular dimensions* here made use of—the steel from Bradford iron appears to be decidedly the best, for single plate magnets, which I have tried. But this superiority, as shewn by the result of combination, is evidently to be ascribed in considerable degree, though not entirely, to the insusceptibility of this steel for the *extreme* hardness of cast steel from the best qualities of foreign iron. The hardness, indeed, approximates that of shear steel from *hoop*-L iron. Still the capability of combining advantageously to a considerable extent constitutes a satisfactory quality in this steel—though inferior to that of the best description of cast steel.

The series X. and XI., representing the powers of steel plates from commonest foreign iron, are very unsatisfactory; the degree of hardness of the different plates being found to be most unequal. The re-hardening, it will be seen, injured, rather than improved, the original condition. This uncertainty of character, however, is not unimportant to have been determined. The determination of the powers in combination, in this case, is not at all satisfactory; because of the neutralizing influence of certain plates (Nos. 2 and 5 in series x., and 1 and 3 in series xi.), the effect of which was to diminish the power of the mass to a considerable, but an uncertain, extent.

A general notion of the comparative powers in combination of these twelve series may be obtained, by casting the eye in succession over the different tables. For a satisfactory comparison, however, of the magnetical qualities of the more characteristic kinds of steel, I have thrown into the form of a diagram (No. 5) the powers of the series No. ii., double shear steel; v., cast steel (hoop-L); vii., blister steel; and viii., cast steel from Bradford iron. So distinctly are the relative magnetical properties of these four kinds of steel here exhibited, in all the varieties of combination up to six plates of each kind, and an aggregate mass, in each, of near 6000 grains weight, as to characterize, I conceive, this method of determining and representing such varied powers as being at once elegant and conclusive.

Before, however, we can be prepared to draw *general* conclusions, as to the relative magnetical qualities, or degree of superiority of any of the various kinds of steel, under the different changes of condition which influence the results, two other elements in the investigation are necessary: viz. the effects of *alterations in the thickness*, or mass of the steel plates; and of *annealing*, or reducing the extreme hardness in the plates, whose magnetical properties have been given in this chapter.

The investigation of the effects of these two conditions, for certain practical objects of much importance, will now be described; postponing the propositional deductions to the end of a subsequent chapter, in order to embrace all the circumstances which seem to affect the General Results.

CHAPTER V.

OF THE MAGNETICAL POWERS OF STEEL PLATES OF DIFFERENT MASSES, DENOMINATIONS, AND QUALITIES, AND MEASURES OF COMBINATION, PREPARED FOR THE NEEDLES OF SEA-COMPASSES — WITH THE EFFECT OF SPACING THE PLATES.

The Investigations of this chapter are in many respects common to others, which have already been described. Herein, however, a further, and very important object was contemplated;—the extension of facts bearing on the general inquiry of this part of the work, and *with direct reference to the improvement of sea-compasses.* Thus the object becomes quite specific. This object may be thus more particularly stated:—*the determination of the best quality and denomination, and degree of hardness of steel, for each of the different limited masses or combinations requisite to be employed in the construction of the directing magnets for sea-compasses.*

About 30 sets of steel plates were employed in these investigations, comprising from 4 to 24 in each set; and a total number of near 300. They were of but two different lengths, 6 inches and 7·5 inches. Their breadths were from 0·42 inch to 0·75 inch. The weights of the 6 inch plates, corresponding very nearly in each set, varied from about 100 to 240 grains; and of the 7·5 inch plates, from about 230 to 430 grains. All but two or three sets were pierced with four small holes, for the convenience of combination as compass needles.

The degree of hardness comprised three general kinds, which were equable throughout their respective plates: viz., a spring temper—quite hard—and particularly annealed.

The *qualities* consisted of best cast steel, ordinary cast steel, cast steel of Stubs' peculiar manufacture, and cast steel from Bradford iron; and the *denominations* embraced those of "cast steel," "double shear steel," and an undescribed kind of steel (apparently cast steel), used at the Mint.

All these plates were magnetized in the same way—that is, to their utmost capabilities; and their powers were tried at the corresponding distance of two lengths of the plates, respectively, from the centre of the compass.

A selection of the experiments are here given, comprising the power of the plates separately;

their powers in combination; their reduced powers after combination, and, with several of the sets, their powers in combination when separated by thin discs of wood.

SECT. I.—*Experiments with Plates for Compass Needles of best cast steel, tempered equably throughout, at a spring temper.*

The particular degree of hardness of all the plates described under this section belongs to the specific kind distinguished in the diagram, Plate II., and in the table of characteristic letters (page 188), by the letter T.

Several series of plates of this description were employed of each of the two lengths of 6 and 7·5 inches. The 6 inch plates were of the uniform breadth, very nearly, of 0·42 inch, and the 7·5 inch plates of 0·5 inch. Their thicknesses, as shewn by the differences of weight, were dissimilar in the different sets.

It should be observed, that the order of the plates, when the powers were tried in combination in the two conditions of "contact," and "separated by discs of wood," was not exactly the same; that is, the plates were not always placed together in the same order of succession. The general results of combination, however, are not affected by this circumstance.

No. of the Plates.	Power of Plates Separately.		Power in Combination.	
	Maximum before Combination.	After Combination.	In Contact.	Separated by Discs of 0·125 inch.
I.	II.	III.	IV.	V.
XIII.—*Best Cast Steel:* 18 Plates of 6 inches: Weight 97·5 grains each. [Tested under a Deviating Power of 30° 58′.]				
	° ′	° ′	° ′	° ′
C. T. 1	6·20	3·0	6·20	6.45
2	6·22	3·46	11·8	12.10
3	6·30	3·8	—	16·45
4	6·50	2·40	18·0	20·33
5	6·33	3·20	—	24·10
6	6·30	3·18	21·55	27·28
7	7·55	1·30	—	30·10
8	6·33	3·20	24·40	32·30
9	6·20	3·0	—	34·45
10	5·45	3·30	26·5	37·20
11	6·50	3·0	—	39·14
12	6·18	2·35	27·10	40·50
Mean	6·34	3·1	—	—
XIV.—*Best Cast Steel:* 23 Plates of 6 inches: Weight, 143·5 grains. [Tested under a Deviating Power of 36° 58′.]				
C. T. 1	10·46	3·50	10·46	10·46
2	10·50	4·30	17·40	17·59
3	10·55	5·47	—	23·15
4	10·20	2·45	23·50	27·15
5	10·22	4·43	—	30·10
6	10·35	2·56	26·30	33·18
7	9·50	3·43	—	35·30
8	10·35	3·10	28·20	37·52
9	10·25	5·27	—	39·48
10	10·12	4·12	30·22	42·30
11	10·30	3·50	—	44·0
12	10·35	4·16	30·45	45·55
18	—	—	—	53·24
20	—	—	34·33	55·15
Mean of 20	10·29	3·56	—	—

No. of the Plates.	Power of Plates Separately.		Power in Combination.	
	Maximum before Combination.	After Combination.	In Contact.	Separated by Discs of 0·125 inch.
I.	II.	III.	IV.	V.
XV.—*Best Cast Steel:* 22 Plates of 7·5 inches: Weight, 231 grains. [Tested under a Deviating Power of 32° 0′.]				
	° ′	° ′	° ′	° ′
C. T. 1	10·15	4·58	10·15	10·15
2	9·45	4·30	16·8	17·30
3	10·22	4·30	19·40	22·30
4	9·45	3·58	21·12	25·22
5	10·4	5·15	—	—
6	10·10	2·45	23·10	30·10
7	9·50	4·40	—	—
8	9·35	1·45	24·50	34·20
9	9·30	4·38	—	—
10	9·50	5·55	26·10	38·10
11	10·15	4·52	—	—
12	9·23	2·25	26·50	40·8
22	—	—	32·0	51·53
Mean of 22	9·54	4·3	—	—
XVI.—*Best Cast Steel:* 19 Plates of 7·5 inches: Weight, 299·5 grains. [Tested under a Deviating Power of 34° 10′.]				
C. T. 1	9·26	5·45	9·26	—
2	9·20	3·50	15·0	—
3	8·58	2·17	18·15	—
4	8·55	0·45	19·32	—
5	9·15	4·30	21·30	—
6	9·22	5·20	23·10	—
12	—	—	28·45	—
19	—	—	34·10	—
Mean of 19	9·26	4.6	—	—

These four tables exhibit the magnetical qualities of *tempered* steel plates, designed for compass needles, constructed in the year 1838. The comparative powers, as combined in *contact*, of those of Table xv., are represented in the diagram, No. 6., in the curve marked as—"Cast steel tempered: *C.* T. 231 grains." The same series of plates, when *separated* by thin discs of wood (0·125 inch in thickness), is found, as in the case of former experiments, to obtain a rapid accession of energy, especially in the larger measures of combination, in the proportion, with 22 plates together, of the tangents of 32° 0′ and 51° 53′, or of 625 to 1275; shewing, ultimately, a doubling of the power by the spacing of the 22 plates. The relation of these powers, as augmented by the separation of the plates to the extent of 13 in number, to those of the same plates in contact, as well as to plates of several other different kinds, is shewn in the diagram No. 6, by the faint line-curve marked with dots.

Tables XIII. and XIV., in like manner, shew the effect of spacing the plates in the progress of combination; but there is no peculiar feature in them that needs to be noticed.

SECT. II.—*Experiments with Plates for Compass Needles, of superior qualities of steel of various kinds and denominations, made quite hard.*

The degree of hardness of the plates here referred to, is very nearly that heretofore indicated by the characteristic letter H. It was in all cases the result of a sudden cooling in a bath of salt and water (except in the case of steel from Bradford iron, which, when plunged into water being found to fracture, was cooled in oil), when the plates had been heated to a cherry-red —no further reduction of the hardness being suffered, than was absolutely necessary, after the manner of the treatment of files, for bringing the plates into form. As this process was accomplished by a first-rate file-maker, the measure of reduction was found to be very inconsiderable.

All the plates employed for the investigations of this section were manufactured at the works of Mr. Peter Stubs, at Warrington; and, for the most part, were pierced for combination in the usual manner. They were of somewhat different forms, as hereafter described. The sizes were correspondent in length to those of the sets used in the preceding section; but the breadth of each class was greater—those of 6 inches long being 0·56 inch broad, and those of

7·5 inches long, 0·75 inch broad. The former were of the average weights, in the respective series, of 119, 123, 136, and 242 grains; the latter of 393, 400, 420, 424, and 427 grains.

These various plates, which were constructed in sets of 4 to 8 of each description, comprised five different qualities or kinds of steel, distinguished in the tables by their characteristic letters—*CS.*, *SS.*, *CL.*, *M.*, and *Cb.*, or cast steel from best Bradford iron.

1.—Experiments with five series of 6 inch compass plates, 0·56 inch broad.

No. of the Plates.	Power in Combination.		No. of the Plates.	Power in Combination.	
	Deviation.	Tangent.		Deviation.	Tangent.
XVII.—*Cast Steel: CS.* H. Weight, 123 grains each.			XVIII.—*Cast Steel: CL.* H. Average Weight, 136 grains.		
	° ′			° ′	
1	5·47	101	1	5·20	93
2	11·0	194	2	10·58	194
3	16·0	287	3	15·28	277
4	19·45	359	4	19·30	354
5	22 30	414	5	23·0	424
6	25·15	472	6	26·22	496
7	28·30	543	7	29·0	554
8	31 30	613	8	32·2	626
Mean	5·40	99	Mean	5·40	99

No. of the Plates.	Power in Combination.		No. of the Plates.	Power in Combination.	
	Deviation.	Tangent.		Deviation.	Tangent.
XIX.—*Shear Steel: SS.* H. Average Weight, 119 grains.			XX.—*Mint Steel: M.* H. Average Weight, 242 grains.		
	° ′			° ′	
1	8·0	141	1	10·50	191
2	14·40	262	2	17·18	311
3	19·45	360	3	22·50	421
4	24·20	452	4	27·0	510
5	28·12	536	5	28·40	547
6	31·10	605	6	31·15	607
7	33·16	656		——	——
8	35·22	710	Mean Power of Plates separately	10·10	179
	——	——			
Mean	7·40	135			

XXI.—*Cast Steel* from *Bradford Iron: C b.* H.

Average Weight of the Plates, 141 grains.

No. of the Plates.	Weight in Grains.	Maximum Power Separately.	Power in Combination.		Power after Testing.
			Deviation.	Tangent.	
[Tested with Test-bar H: Deviating Power, 34° 48′].					
		° ′	° ′		° ′
1	147	10·35	10·35	187	7·10
2	144	10·28	17·56	324	7·10
3	139	9·54	23·31	435	7·15
4	135	10·3	27·41	525	7·23
	——	——	——	——	——
Mean	141	10·15	—	181	7·14

2.—Experiments with five series of Compass Needle Plates of 7·5 inches in length, and 0·75 inch in breadth.

No. of the Plates.	Power in Combination.		No. of the Plates.	Power in Combination.	
	Deviation.	Tangent.		Deviation.	Tangent.
XXII.—*Cast Steel: CS.* H. Average Weight, 427 grains.			XXIII.—*Shear Steel: SS.*H. Average Weight, 400 grains.		
	° ′			° ′	
1	9·33	168	1	13·3	232
2	16·10	290	2	21·25	392
3	23·38	438	3	27·25	519
4	29·15	560	4	31·0	601
5	33·38	665	5	34·20	683
6	37·0	754	6	36·50	749
7	40·18	848	7	37·17	761
8	42·13	907	8	38·7	785
Mean	10·7	178	Mean	12·44	226
XXIV.—*Cast Steel: CL.* H. Average Weight, 424 grains.			XXV.—*Mint Steel: M.* H. Average Weight, 393 grains.		
1	9·5	160	1	8·12	144
2	17·0	306	2	15·40	280
3	23·30	435	3	21·30	394
4	28·20	539	4	27·15	515
5	33·20	658	5	32·49	645
6	36·55	751	6	36·15	733
Mean	9·14	163	Mean	8·52	156

XXVI.— *Cast Steel* from *Bradford Iron*: *C b.* H.
Average Weight of the Plates, 420 grains.

No. of the Plates.	Weight in Grains.	Maximum Power Separately.	Power in Combination.	
			Deviation.	Tangent.
		° ′	° ′	
1	405	13·8	13·8	233
2	435	14·0	21·32	395
3	412	13·26	26·40	502
4	430	13·28	30·0	577
Mean	420	13·30	—	240

The mean powers of the four series of plates, XXII. to XXV., individually, as tested under a combination having a deviating energy of 50° 40′, were as follow:—Series XXII. 6° 34′; XXIII. about neutral; XXIV. 7° 7′; and XXV. 9° 19′.

In the ten series of hard steel plates—that is of plates of different kinds of steel, hardened in a corresponding manner and at a similar heat—we find the superiority, in simple magnetic capacity, of the steel from Bradford iron, still preserved. But this advantage only extends to single or double plates; as beyond double plates the best *shear steel* is found superior. In the five series of 7·5 inch plates, it may be observed, that whilst the powers of the plates of each kind, singly, are very dissimilar, the inequality gradually diminishes in combination; and that on a combination of six plates of each of the four series, commencing with the twenty-second (the total weight of such combination being about 2400 grains), a remarkable coincidence in the powers of all the kinds occurs:—the powers of six plates of the four series referred to, being respectively, 37° 0′, 36° 50′, 36° 55′, and 36° 15′. Beyond this extent of combination, the *cast* steel, according to the general law, takes the lead, and ever afterwards retains its pre-eminence.

The magnetical powers of the principal kinds of steel, as exhibited in the compass-needle plates of 7 5 inches in length, are represented in the diagram, No. 6. The scale on which this diagram is constructed is just treble that employed in the previous one, No. 5; but as both the scales of "tangents" and "weights" are in the same ratio, the analogy of the diagrams is correctly preserved. The powers of the 6 inch compass plates were, in like manner, projected in a diagram; but the general character of the curves was so very similar in the two diagrams, that it did not appear worth while to engrave both of them.

As the effect of reducing the hardness of these various kinds of steel, was still necessary to be determined, before any general conclusions as to the best steel and temper for compass needles could be satisfactorily drawn,—I have reserved the propositional results until the completion of the Investigations on all the conditions requisite to be examined, which have been already noted, as affecting the magnetical powers of steel.

CHAPTER VI.

ON THE EFFECTS OF THE *ANNEALING* OF HARD STEEL PLATES OF DIFFERENT KINDS AND MASSES, ON THEIR MAGNETICAL QUALITIES, BOTH SINGLY AND IN PAIRS.

THE term *annealing* I here employ, in the sense in which it is ordinarily used in the arts, to designate the process by which brittle substances are, by the peculiar application of heat, reduced in their hardness, and rendered less liable to break. The actual result of the process, indeed, in the case of magnets or other articles made of steel, is the same as *tempering;* and I merely employ another term to indicate a process different from, or a result gained in a more satisfactory manner by such process than by, that in ordinary use among smiths and cutlers.

In the Investigations of Part I. chapter V., the *general* effects of various degrees of hardness on the magnetical capabilities of *best cast steel,* were determined, together with the modifications resulting from varieties of size and mass. The results thus obtained, however, only afforded the general laws of that particular denomination—"cast steel," with the special powers, in respect to the leading conditions by which the magnetic energy is affected, in the same.

For the determination of the best quality, denomination, and degree of hardness of the magnets designed for sea-compasses—an inquiry of great, indeed of national importance—further investigations became necessary. All that seemed needful to be done in respect to *quality* and *denomination*, indeed, has been brought forward in the last chapter. But inasmuch as great differences are found to exist in the capacities of perfectly hard plates, suitable for compass needles, in steel of different *denominations*, especially betwixt the powers of *cast* steel and *shear* steel; and as the capacity of hard *cast steel* is found, when in single thin plates, to be very inferior to that of either tempered cast steel, or unreduced shear steel,—it became desirable so to determine the effects of annealing, that both the best condition for compass needles, in the several denominations, might be ascertained, and some fixed mode and standard of reduction might be obtained for practical use.

The condition, as to temper, of the bars and plates heretofore employed in these Magnetical Investigations, was, with but comparatively few exceptions, that into which the bars and plates, respectively, had been brought by the artizan or manufacturer who supplied them. But it was found that, in many cases, the plates or bars of any particular set, *ordered* to be of a certain, technically-understood, temper, and *intended* by the manufacturer to be of such temper uniformly, were of very different degrees of hardness; and that the temper of different sets, expected to be alike, was also very dissimilar.

Hence it became obviously desirable, for obtaining the most effective practical results, that some mode of tempering should be determined by which a more perfect measure and accordance in hardness might be obtained. In order to this, certain conditions, which seemed to be reasonably attainable, at least within definable limits as to size and mass in the plates or bars of steel employed, would be practically necessary. If the steel plates were to be reduced, or "let down," *after* being uniformly hardened to their utmost capability, then the condition would be—to obtain the equal reduction of the hardness by an exposure to a determinate and equable degree of heat: and if the effect were to be obtained by the simple and direct process of hardening to any particular degree from the state attained in being forged,—then all the plates must be exposed to an uniform and specific degree of heat, and suddenly cooled in the same precise manner, and with corresponding rapidity.

This latter process is the one recommended in many of our books, treating of the construction of artificial magnets. Dr. Gowan Knight, M. Coulomb, and others, were wont to employ, for some of their magnets, this process, tempering or hardening steel bars, by the first intention, "at a cherry-red heat."*

An important fact, however, in the phenomena of tempering, shews that this method will be very uncertain, and unequal in its results: viz. that the resulting degree of hardness depends, not on the heat to which the steel is raised only, but on the degree of heat taken in connexion with the rapidity of cooling. Hence very small steel wires, or extremely thin plates, may be brought to a suitable temper for drills or springs by being heated to a blood red and then cooled in a current of air; whilst the same process would produce in masses of considerable thickness, a very slight change from the original soft state. And, in like manner, thin plates or needles, plunged into cold water when heated to a blood-red colour, will be found as brittle as glass; whilst thick bars, treated in the same way, will not be hardened, perhaps, beyond the ordinary degree of cutting instruments.

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* Brewster's Treatise on Magnetism, pp. 284, 292, etc.

For the trial of this method, I employed several six-inch bars of cast steel of different thicknesses. Some of the bars, half an inch square, when only heated to this degree of redness (blood or cherry red), and then plunged into cold water containing some salt, were found to be of a very low temper, so that they could be easily filed; the effect, however, was by no means uniform. Other bars of the same length and breadth, but only one-tenth of an inch in thickness, became, by the like treatment, considerably harder. One of these thinner bars, for instance, weighing 634 grains, being heated in an open parlour fire to a low red, not near to cherry red, and then cooled in spring water, was found to have a maximum capacity for magnetism, equal to a deviation at two lengths from the compass of 19° 10′, which fell, on the application of the test-bar H, to 5° 50′. The same bar, heated in a stove to full cherry red and cooled as before, had its magnetical capacity increased to 22° 30′ deviating power, with a power of 14° 28′ after the action of the test-bar. From the guidance afforded by the table at page 57, it appears, that the degree of hardness, in the first instance, was greatly below that of spring temper, T; whilst the temper obtained, in the second instance, was somewhat harder than that of ordinary cutting instruments,—about the same as would take place in hard cast steel, if "let down" by being heated, until the progress of oxidation had produced a straw colour on the surface.

This mode of tempering—varying in the result with the thickness of steel subjected to it, and rendered further variable, even in plates or bars of similar dimensions, by reason of the uncertainty of the degree of heat as determined merely by the hue of the incandescence—could not therefore be employed with any satisfaction for the purpose contemplated; viz. for obtaining an uniformity in the degree of hardness of different plates or bars of steel.

Hence some method, analogous in its steps to that employed by cutlers and smiths—the steps being first to harden to a state of brittleness, and then to reduce by the action of a moderate specific degree of heat—afforded the best prospect of attaining the desired object. In order, however, to this method being made effective, a tolerably uniform degree of extreme hardness would be requisite to be obtained as the first condition in the process. And this condition, especially in masses not greater than those employed in the investigations of the last two chapters, is found to be much more easily attainable than uniformity of a lower temper—because very great differences, within given limits, in the heat at which the plates are plunged into water, occasion but comparatively little variation in the resulting hardness.

The practicability of producing the required uniformity, in extreme hardness, in the corresponding plates of any particular set constructed out of the same bar of steel, is shewn by the results of the experiments on hard plates of cast steel and shear steel, in chapter IV.; especially in the sets V. VI. VIII. and IX.—in which the general equality of the powers of all the plates of each set, respectively, both as to their separate capacity, and as to their powers after combination, shews the satisfactory equableness of their degree of hardness.

This principle, therefore,—the *annealing* of bars or plates, first made as hard as possible, by subjecting them to the same exact degree of heat,—promised to afford something like the uniformity of temper required to be produced. And if this should be accomplished, then might we determine with the greatest precision, the relative magnetical qualities of any particular temper, or degree of reduction of the extreme hardness; and at the same time we should secure a method whereby such precise temper might, in the use of like kinds of steel, in all cases be obtained.

This investigation embraced several points of inquiry essential to the attainment of satisfactory results:—such as, Whether there might be any difference, in effect, betwixt a momentary application of heat to the hard plates, and the continuation of the same heat for a considerable period? Whether any difference might arise from the method of cooling the plates at the conclusion of the annealing process? What might be the relative effects of annealing, at any given heat, on the various kinds and denominations of steel? What might be the relation betwixt the degree of heat employed and the measure of reduction in the hardness? What might be the effect, on the same bars, of repeating the annealing process? And finally, whether hard bars of different *forms*—such as the straight bar and horseshoe forms—are similarly affected, as to their magnetical qualities, by annealing?

Each of these points of inquiry was made, in some measure or degree, the subject of particular investigation by experiment.

The modes which occurred to me for the application of determinate and equable degrees of heat to the hard bars or plates to be annealed, proved to be the same as had been previously employed by Mr. Nicholson and Mr. Stodart. Supposing that a higher degree of heat would be requisite for the reduction of hard plates to a spring temper, than what really proved to be needful, I commenced with a bath of melted lead in a vessel constructed for the purpose. The rapid change of colour of the plates, however, when laid upon the lead, just brought to a state of fluidity, shewed that the heat thus applied was already at a maximum. At the same time the method was not a very convenient one, as the steel was liable to become partially plated with lead, unless very carefully protected.

From lead I proceeded to a bath of linseed oil raised to a high temperature. Not having, in the first trials, a thermometer suitable for the determination of the progressive rise of temperature, I was obliged, that the results might be satisfactory, to proceed to the heat of boiling oil.* The effect, as will be seen, was, on some descriptions of plates, much greater than was required; but the effect produced, was still sufficient to guide to certain important practical results.

Finding, however, that this subject was of essential importance for the completion of the series of investigations in progress, I subsequently repeated the experiments on annealing at various degrees of heat from 300° to 550° inclusive, as indicated by the thermometer. The particulars of each class of experiments are annexed.

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* The temperature at which linseed oil, and other fixed oils boil, is stated to be about that of 600°.

SECT. I.—*On the Effects of Annealing hard Steel Plates in boiling Linseed Oil.*

Two series of experiments, under this head, will be sufficient to be described—embracing, as these do, all the points which have been satisfactorily determined.

1. The first series consisted of twenty-four plates of seven different kinds as to denomination, quality, or dimensions. They were chiefly thin plates prepared for the construction of compass needles. All of them had been hardened originally to the utmost degree; but some had been subjected to a very slight reduction in putting them into form, after the manner of the treatment of files. These plates being tied up in two nearly corresponding bundles, comprising equal portions of the several kinds of plates, were placed in a kettle of pure linseed oil, in the progress of being heated. A few minutes after the oil was brought to the boiling point, which required a considerable time, the two bundles were removed, and one of them was laid on the flags to *cool gradually* in the air, and the other was *plunged into cold water.*

Table XXVII.—Effects of Annealing at the heat of boiling Oil (A B), on various descriptions of hard Steel Plates, H., designed for Compass Needles.

Description of Plates.				Powers when hard.			Powers after annealing.		
No. of the Set.	Characteristic Letters.	Length in Inches.	Weight in Grains.	Maximum Single.	Deviation in Pairs.	Tested by Bars H or D.	Maximum Single.	Deviation in Pairs	Tested by Bars H or D.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
				° ′	° ′	° ′	° ′	° ′	° ′
XVII.	*CS.*	6·0	123	5·40		4·37	9 3		2·24
				5·58	11·4	5·1	8·37	15·7	1·56
XVIII.	*CL.*	6·0	136	4·13		3·30	8·38*		3·48
				5·0	10·12·	3·42	9·22*	15·32	3·53
				5·0		3·53	8·44		3·45
				5·37	10·8	4·57	9·9	15·18	3·25
XIX.	*SS.*	6·0	119	7·27		5·32	9·51*		−4·18
				7·2	13·14	5·37	9·42*	15·13	−4 30
				7·16		6·13	9·28		−4·3
				7·20	14·40·	6·10	9·29	14·43	−4·12
XXII.	*CS.*	7·5	427	9·25		8·42	14·12*		+10·42
				9·20	16·10·	8·36	14·17*	21·28	10·37
				9·28		8·44	14·2		10·50
				9·33	17·22	8·53	14·4	21·23	10·43
XXIII.	*SS.*	7·5	400	12·7		9·45	13·30*		4·14
				12·30	21·25·	—	13·52*	18·6	4·32
				12·16		10·30	13·37		4·47
				12·30	20·45	10·55	14·4	18·6	4·51
XXIV.	*CL.*	7·5	424	8·44		8·14	14·3 *		11·6
				9·23	16·39	8·40	14·23*	21·33	11·5
				9·50		9·15	13·48		11·0
				8·43	17·0·	8·12	14·23	21·25	11·15
IV.	*C.*	7·5	590	15·25		14·20	18·20*		14·32
				15·32	26·0	14·25	18·30		14·47

The experiments on the effects of annealing are here thrown into a tabular form, as the most convenient, with a reference in col. I., by Roman numerals, to the set of plates in the foregoing tables, to which each of these plates respectively belongs. Those suddenly cooled, when taken out of the boiling oil, are distinguished in the table by an asterisk in col. VIII. The powers of the plates *in pairs*, as shewn in cols. VI. and IX., were determined when the plates of each pair were in even contact. Some of the powers of *pairs* in col. VI. were supplied from the former tables, and are here distinguished by a dot after the figures. All the powers here registered are those of the influence of the magnetized plates on the needle of a compass at the distance of twice the length of the plates respectively.

In addition to the particulars herein notified, in respect to the magnetical powers of the plates under the different circumstances referred to—a further inquiry was carried on at the same time: viz. as to the effect of the annealing process on the degree of magnetic energy possessed by each plate when first placed in the oil: in other words, as to the quantity of energy lost by the operation? The result of this inquiry is noticed in a future place.

The only observation, in anticipation of the summary of General Results, which occurs to me as being called for at this position of the Investigations on the Effects of Annealing, is the striking and important differences in the effects of the process on the two denominations of *cast* and *shear* steel. In the limited measure of combination here employed—extending only to pairs of plates,—and in the general thinness of the plates subjected to the process, not exceeding, except in the last two, the thirtieth of an inch,—the *cast* steel in every case *gained* in magnetic capacity by the annealing; but the *shear* steel derived comparatively small advantage, even in the individual or separate capacity of the plates, whilst in combination there was a *loss* of capacity, even in a pair of 7·5 inch plates weighing together only 800 grains. In larger numbers in combination, the annealing in boiling oil was found to be every way injurious for magnetical purposes. The effects may be perceived by mere inspection of two of the dotted curves in the diagram No. 6—representing the powers of two kinds of annealed plates—shear steel of 400 grains, and cast steel of 424 grains, each, and in combinations of four and six plates.

2. The results obtained by a second trial of the effects of the annealing of hard steel plates in boiling linseed oil, are shewn in the following table. The experiment in this case extended to a still greater variety of plates or bars (all being originally of the hardness designated by the characteristic letter H); but the mean powers only, of each variety, are here given. An additional column, No. xi., shews the number of plates of

each description employed in this investigation; and though two columns are omitted from the series included in Table XXVII. yet the numbers of the similar columns are made correspondent in these two tables.

Table XXVIII.—Effects of Annealing on various kinds of hard Steel Plates, H.

Description of Plates.				Powers when hard, H.		Powers after Annealing, A B.		Amount of Plates used.
No. of the Set.	Charact. Letters.	Length.	Weight.	Mean Single.	Mean in Pairs.	Mean Single.	Mean in Pairs.	
I.	II.	III.	IV.	V.	VI.	VIII.	IX.	XI.
The following 5 Sets were immersed for two minutes in boiling Oil, and then plunged into cold Oil.								
				° ′	° ′	° ′	° ′	
XVII.	*CS.*	6·0	123	5·56	10·55	8·33	15·6	4
XVIII.	*CL.*	6·0	136	5·28	10·13	9·19	16·9	4
XX.	*M.*	6·0	242	10·23	17·18	12·42	20·10	2
XXII.	*CS.*	7·5	427	9·4	16·10	13·51	21·47	2
XXIV.	*CL.*	7·5	424	9·15	17·0	14·8	21·53	2
The following Plates were 30 minutes in boiling Oil, and gradually cooled in the Air.								
XXII.	*CS.*	7·5	427	10·16	17·50	14·27	22·1	4
XXIV.	*CL.*	7.5	424	8·54	16·20	14·31	22·25	2
II.	*SS.*	7·5	912	23·40	35·20*	16·8	19·50	2
I.	*CS.*	7·5	1000	22·34	33·32*	20·38		
VIII.	*Cb.*	7·5	1005	27·46	38·45	17·38	20·20	2
X.	*C cf.*	7·5	940	24·15	25·30*	15·12	17·40	2
XXV.	*M.*	7·5	394	9·38	15·40*	14·8	—	1
—	*C.**	7·5	694	14·15	25·15	19·16	25·10	2
—	*B.*	7·5	640	17·24	—	15·6	—	1

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* These plates were taken from a set not included in the varieties of the foregoing tables. The set consisted of plates constructed for compound compass-needles, made of cast steel, and of the hardness approximating the degree H.

The general correspondency of the conclusions derived from this experiment, with those of the foregoing table (No. XXVII.), renders any particular observations, in this place, unnecessary. The principles and deductions flowing from the investigations, will have their proper place in the General Results.

SECT. II.—*On the Effects of Annealing, on hard Steel Plates, in hot Oil, at various Degrees of Temperature.*

Hitherto these investigations, in regard to the magnetic powers of steel as affected by degrees of hardness, have proceeded, mainly, on a comparison of the several ordinary distinctions of temper familiar to cutlers and smiths, and herein indicated by the characteristic letters S. E. T. H., together with the preceding experiments on the annealing in boiling linseed oil, AB. corresponding very nearly, in the effect on cast-steel, with the ordinary spring temper, T.

But whilst under these specific conditions, the advantage, as to magnetic capacity, was found, on all trials with straight bars of steel, to be in favour of the greatest hardness, when either large masses or combinations of many plates or bars were to be employed; it by no means followed that no condition of hardness intermediate betwixt H and T (a large interval as to the degrees of hardness), might not afford a capacity for a higher measure of magnetic energy, for less considerable masses or combinations.

My attention was, in the first instance, directed to the case of straight-bar magnets; though I certainly did not anticipate the difference that was actually found to take place when the bars were turned into the horse-shoe form.

Thus far my investigations on the subject of annealing had proceeded, when a notice of the results on the tempering of steel, obtained in the course of the inquiries of Dr. Faraday and Mr. Stodart, on the effects of various alloys, etc. fell into my hands. From the effects of annealing, as shewn in the last two Tables XXVII. and XXVIII., I had previously inferred (immediately, indeed, on the completion of the experiments), that many of the plates had been reduced in hardness *below* that of the best temper for compass needles. The deductions of Mr. Stodart confirmed this inference, and, at first sight, appeared in considerable measure to have superseded the necessity for the further inquiry I had contemplated; that is, as to the connexion betwixt the degree of heat applied to hard steel, and the resulting temper, or the measure of reduction, in the hardness.

A little consideration, however, made it evident that the subject was of so much importance as to call for special investigation on the principles, and by the mode of testing, etc. already so extensively pursued; without which, indeed, the actual effects of various degrees of heat on the magnetical properties of hard steel bars could not be really known.

Having provided myself with a chemical thermometer, graduated up to the boiling point of mercury, with a stove expressly constructed for the convenient heating of the oil, I proceeded with this investigation, in accordance with the methods, so far as herein applicable, which had been adopted for the experiments (Sect. I.) on the annealing in boiling linseed oil.

Six sets of plates and bars (all the plates being 7·5 inches in length) were subjected to this experiment on annealing at various temperatures. These consisted of *shear steel* plates, belonging to set No. III. in the foregoing tables; *cast steel* plates of set No. I; cast-steel plates of a set designed for compass-needles described at the foot of Table XXVIII.; *shear-steel* plates for compasses, of the set No. XXIII.; *cast-steel* plates of like description, of the sets Nos. XXII. and XXIV., together with the bars of a new five-bar horseshoe magnet made by Messrs. Stubs, the results obtained with which belong to the next section. All these plates and bars were, at the commencement of the experiments, in their original state of *extreme hardness.*

These being arranged in six different sets, so that they might conveniently be subjected to the various degrees of heat designed, were placed in succession in the vessel of oil whilst on the fire. As the thermometer rose to each of the required temperatures of 300°, 350°, 400°, 450°, 500°, and 550°, one of the sets was removed and plunged into cold oil. The effect of the temperature of boiling oil having been before investigated, was not now repeated, but the results supplied, chiefly, from former experiments.

Previous to the annealing of the various plates and bars, their maximum magnetical powers were determined, both singly and in pairs, by the deviations at two lengths from the compass; and their strength, or tenaciousness of the magnetic condition, was likewise ascertained. After the annealing, the same qualities were again determined. I regret that the mode of testing before and after the annealing, was not the same. In the former case, the test was derived from a miscellaneous combination of the plates themselves, exhibiting, in the mass, the required energy; but this test, where the plates or bars are of various degrees of tenaciousness, as must be the case where shear-steel and cast-steel are combined, was found not to be very consistent or decisive. But in the latter instance (the testing *after* the annealing) the results were obtained by placing each plate in succession betwixt two bundles of hard cast-steel plates of the required energy, and these results were found quite satisfactory. Tables XXIX. to XXXIII. comprise the whole of the particulars, in regard to the several series of plates, which seem to be necessary for the object contemplated. All the plates, it should be remembered, were of the same length, viz. 7·5 inches.

Maximum Powers before Annealing.			Powers after Annealing.			
Deviation Single.	Deviation in Pairs.	Tested under Power of 50°.	Temperature of Oil.	Deviation Single.	Deviation in Pairs.	Tested under Power of 50°.
I.	II.	III.	IV.	V.	VI.	VII.
XXIX.—*Shear Steel: S* H. [Table III.] Average Weight, 623 Grains.						
° ′	° ′	° ′	°	° ′	° ′	° ′
17·36*	25·40	5·3	300	18·4*	26·3	— 1·10
17·24*	28·18	9·6	350	17·12*	27·20	+ 2·0
17·23	26·38	3·27	400	17·12	24·34	— 1·5
18·13		4·30	450	18·5		— 6·50
15·33	24·57	4·40	500	15·33	20·33	— 8·45
15·58		2·52	550	15·28		—10·15
16·37*	. . .	3·44	Boiling	15·37*	. . .	— 9·36
16·58	26·23	4·46	450	16·44	24·37	— 5·6
XXX.—*Cast Steel: C S* [Table I.] Average, 977 Grains.						
17·50	32·56	15·18	300	17·28	31·54	14·35
20·46		18·0	350	20·45		16·50
18·55	33·42	15·0	400	19·22	32 50	13·40
22·8		17·40	450	23·18		10·40
19·45	32·0	16·35	500	22.26	29·27	2·5
18·3		15·27	550	22·6		0·52
18·0*	. . .	15·22	Boiling	21·34*	. . .	0·37
19·21	. . .	16·12	450	21·0	. . .	8·18

* The deviations, with an *asterisk* annexed, are the means of a pair of similar plates. Those with a *dot* annexed, were supplied from former experiments, in one or two cases derived proximately from such experiments.

Powers before Annealing.			Powers after Annealing.			
Deviation Single.	Deviation in Pairs.	Tested under Power of 50°.	Temperature of the Oil.	Deviation Single.	Deviation in Pairs.	Tested under Power of 50°.
I.	II.	III.	IV.	V.	VI.	VII.
XXXI.—*Cast Steel*, Plates for Common Needles, *C* H. Average Weight, 694 Grains.						
° ′	° ′	° ′	°	° ′	° ′	° ′
14·38	24·13	10·32	300	14·2	25·6	9·58
14·0		4·42	350	15·28		7 35
14·38	26·28	10·32	400	14·57	26·0	8·50
14·53		10·52	450	17·5		6·13
15·22	26·50	12·45	500	18·12	25·48	1·35
15·10		12·35	550	18 2		— 1·56
. . .	. . .	. . .	600 B	19·31*	25·38	— 3·35
14·42	25·50	10·20	450	16·45	25·38	7·7
XXXII.—*Shear Steel*, 7·5 inch Plates for Compass Needles, *S*. [Table XXIII.] Average Weight, 402 Grains.						
12·30	21·0·	—	300	12·26	21·42	4·2
12·40			350	12·50		4·0
12·17	20·45·	—	400	12·47	20·55	— 1·0
12·29			450	13·12		— 2·30
12·40	21·0·	—	500	12·48	18·47	— 5·48
12·30			550—	13·17		— 9·59
12·23*	20·45	—	600 B	13·52	18·6	—11·11
12·30	20·52	—	450	13·2	19·52	— 3·12
XXXIII.—*Cast Steel*, 7·5 inch Plates C and *L*. [Tables XXII. and XXIV.] Average Weight, 427 Grains.						
10·40	18·20·	6·52	300	10·16	18·6	7·0
10·40		7·25	350	10·0		6·45
9·5	17·6·	7·30	400	9·23	18·20	6·36
10·0		8·0	450	10·58		6·48
10·40	18·20·	7·25	500	12·4	21·36	2·56
10·40		6·52·	550—	13·28		—4·18
9·4*	17·0	6·50·	600 B	14·11	21·30	—5·22
10·7	17·41	7·16	450	11·29	19·53	2·55

These results, I may venture to state, are, in an experimental and scientific view, very satisfactory and beautiful. The second plates in each of the Tables XXIX., XXX., and XXXI., exhibit, indeed, a measure of discrepancy; but column III., wherein the effect of the testing is represented, shews that in each of these cases the particular plate in question was of a peculiar degree of original hardness, being, in the first two cases, harder than the others, and in the third case very much softer. But altogether the series of changes in the magnetic capacity of the separate plates, and in their degree of tenaciousness, resulting from change of hardness, is, in each set of plates, strikingly consistent and instructive.

The *shear-steel medium* plates, it will be observed (Table XXIX.), derived no advantage of any importance by annealing, even in the lowest degree, in their individual capacity, whilst in pairs, there was an actual deterioration in capacity, at temperatures above 300°, rapidly augmenting with the increase of the heat. The result with *thin* plates, (Table XXXII.) exhibited a very slight gain of individual energy, but at the expense of a formidable deterioration in fixidity, with an absolute loss of energy in pairs of plates when the heat extended beyond 420° to 450°. The *cast-steel medium* plates (Table XXX.), for the most part, gained a little by the annealing, up to the heat of boiling oil; but in pairs, they exhibited, in every case, a deterioration, increasing with the degree of temperature to which the plates had been subjected. In the *thin* cast-steel plates, designed for compass needles, we find, as was reasonably to be anticipated from the previous experiments, a general improvement, (that is, after the first two of the series, which, being supplied from other experiments, are not equally satisfactory) the improvement extending to the powers of pairs of plates, as well as of single plates, throughout the series of temperatures. In the case of the plates, however, of intermediate thickness (Table XXXI.), we find, in perfect consistency with all previous conclusions, the gain, by annealing, limited mainly to the magnetical capacity of the plates separately,—a decided loss being found to take place in all the combinations annealed at a higher temperature than 400°.

SECT. III. — *On the Effects of Annealing, at various Temperatures, on the Magnetic Powers of hard Steel Bars, single and compound, of the Horse-shoe form.*

It yet remained to be ascertained experimentally, the effect of annealing on the magnetic capacity of hard steel bars of the horse-shoe form. So far as my experiments had hitherto gone, powerful combinations of the horse-shoe form derived, like those of straight bars, a decided advantage from hardness. In the instance of the large magnet, described at page 171, the permanent lifting power was more than doubled (nearly trebled) when the several bars, which, in their original state, were quite soft except for three or four inches near the poles, were moderately hardened nearly throughout their extent. It seemed reasonable to expect, therefore, from the previously observed analogies, found to be consistent in every considerable combination of hard straight-bar magnets, that the same law would hold in respect to powerful combinations of the horse-shoe form. The result of actual experiment, however, occasioned me, I confess, much surprise. The law, as to the *general* advantage of hardening the bars throughout, and that to a considerable degree, was amply verified; but the effect of *extreme hardness* was essentially different from what had been anticipated.

Two beautiful compact magnets, constructed for me by Messrs. Stubs, one of five bars, the other of fifteen, in which the bars were of fine cast steel, hardened to the extent and brittleness of files, were employed for investigating the law as to the best kind of temper, or measure of hardness, for instruments of the horse-shoe form. The bars of the smaller magnet weigh 4080 grains each; altogether 2·914 lbs. They measure from the extremity of the curve to the poles six inches, an inch in breadth, and, when combined, an inch in thickness. They are finished flat and even at the poles. Those of the large magnet, weighing together 8 lbs., are arranged differently,—the three centre-bars being the longest, and constituting at their poles an even surface, but the others receding, by steps, being successively shorter by the sixth of an inch. Thus the full length of the centre bars, from the extremity of the curved end of the instrument to that of the poles, is 5·8 inches, whilst those the most remote from the centre, being the shortest, measure 4·8 inches. The entire thickness of the fifteen bars in combination is 2·9 inches.

Each magnet was furnished with conductors of good soft iron, made at different times, of a variety of forms and sizes, in order to the selection, for general use, of the best. The bars of both were magnetized, likewise, in a variety of ways—the method found to be the most effective, generally, here failing,—and that communicating the greatest power adopted for the trial of the instruments.

But, to my great disappointment, the bars were found extremely unenergetic, and their combined powers not equal to some of those of the commonest construction! The average sustaining power of the bars, separately, was scarcely 3 lbs., or about five times their weight. The five-bar magnet carried, when first magnetized, and before the conductor was removed, 21 lbs.; but after the contact had been broken it would only sustain 13 to 14 lbs. The fifteen-bar magnet received a sustaining power of 33 lbs., which fell to 26 lbs. after the breaking of the contact. These powers, I considered very unequal to what was to have been expected from the number of the bars, the quality of steel, and the mode of construction. The effect of reducing the extreme hardness, therefore, became an important inquiry.

I commenced with the five-bar magnet, and having determined the maximum sustaining power of each bar in its original state, by a spring balance, I placed the several bars in heated oil, subjecting each one to a different temperature; viz., one to that of 300°, and others to the several temperatures of 350°, 400°, 450°, and 500°. On their attainment of the desired heat respectively, they were plunged into cold oil. The sustaining powers were again determined, and found to be improved, especially in those that had been subjected to the highest temperatures. The power of the five-bars, when combined together, was likewise ascertained, and found to be considerably augmented. Their retentiveness, with a view to further comparison, was also proved by the degree of energy remaining in each after being separated.

The same bars were, in the next place, all subjected to an uniform temperature in oil heated to 480° of Fahrenheit's scale, and their powers separately, in combination, and after their being again taken asunder, determined as before. But as the powers did not prove to be uniform, and as the bar, which had been heated to 500°, was much more powerful than the rest, a further experiment was made by subjecting the whole to the same maximum temperature of about 500°. Still, however, the powers of the several bars were not so generally accordant as was to have been expected,—the first three in the series being found to be feebler than the remainder, as if they had not been heated fully to the required temperature. And this, doubtless, from a defect in the experiment, was the fact.

A fourth, and final, experiment was therefore made, by placing the bars again in the oil, and heating it up to 500° (or rather 505°, the temperature which the oil ultimately attained), and keeping up the temperature for about a quarter of an hour before the removal of the bars. Hence there was every reason to believe, as the results indicated, that the bars had acquired the same temperature as the oil.

The results of these several experiments are exhibited together in the following Table.

Table XXXIV.

No. of the Bar.	Maximum Powers in the hard state H.	Powers after Annealing.			Powers after Annealing.		
		Temperature of the Oil.	Maximum Power of each Bar.	Power as reduced by combination.	Temperature of the Oil.	Maximum Power of each Bar.	Power as reduced by combination.
		First Annealing.			Second Annealing.		
	lbs.	°	lbs.	lbs.	°	lbs.	lbs.
1	2·5	300	3·2	2·0	480	5·9	2·9
2	2·5	350	3·4	1·9	480	6·4	3·9
3	3·5	400	4·4	2·1	480	5·8	3·6
4	2·3	450	6·0	4·0	480	8·0	4·5
5	3·5	500	8·5	6·0	480	9·2	5·9
Mean	2·9	400	5·1	3·2	480	7·0	4·2
		Third Annealing.			Fourth Annealing.		
1	2·5	500	7·2	Not	505	7·9	Not
2	2·5	500	7·4	tried.	505	8·6	tried.
3	3·5	500	6·8	—	505	7·3	—
4	2·3	500	8·0	—	505	9·7	—
5	3·5	500	8·7	—	505	8·7	—
Mean	2·9	500	7·6	—	505	8·4	—

It should be observed, however, that the sustaining powers of the several bars, as here represented, can only be considered as proximate;—as this mode of trial of the power of magnets is liable to so many differences from the varieties of surface, size, and degree of softness and quality of the conductors; as also from the measure of accuracy with which the surfaces of the magnet and conductor fit each other, as well as from the direction of the strain by which the adhesion of the conductor is tried. But, in order to the obtaining of results as satisfactory as possible, two rules were observed:—1st. To take that amount of tension, as the proper power of the magnet, which could be sustained after the contact of the conductor with the magnet had been at least once broken after any repetition of the magnetizing process: and 2dly, to take, as the maximum power, generally, the highest power that had been twice obtained.

The gradual advancement of the average attractive powers of this series of five horse-shoe bars, by annealing at successively higher temperatures, up to that of 505°, is very striking and conclusive. For here we find the mean power of each bar of the series which, when quite hard (H), was represented by the sustaining of a weight of 2·9 lbs., increased, when annealed at an average temperature of 400°, to 5·1 lbs.; at 480°, to 7·0 lbs.; at somewhat less than 500°, to 7·6 lbs.; and when annealed at 505°, increased to 8·4 lbs. The reasons for going no further in the reduction of hardness, we shall see immediately.

The total lifting power of this magnet, in its final condition, was 25 to 26 lbs., after the repeated removal of the conductor. On the first trial, after being re-magnetized, it sustained a weight of above 38 lbs., before the conductor separated.

Thus, by this measure of annealing, we find that the separate powers of the bars were trebled, and the permanent power of the magnet, as a whole, was doubled. The sustaining powers, in comparison of the weights of the magnets, were equally satisfactory;—the entire magnet being now found capable of supporting nearly nine times its own weight, permanently, and each of the bars, separately, about fifteen times their weight respectively.

Such was the satisfactory nature of the results progressively obtained in the experiments on the annealing of a five-bar magnet of the horse-shoe form,—that I was encouraged to proceed to treat, after a similar manner, the large magnet of fifteen bars. The first trial of the effect of annealing on this instrument was made along with the other in the third experiment. The result, however, was not conclusive. For the thermometer having risen rapidly, and the boiler having been removed from the fire, on the first indication of a heat of 500°, and the magnets immediately taken out, the full degree of temperature intended had not been acquired by the steel. Hence these fifteen bars, which, in their originally hard state, possessed a lifting power, on an average, of about 2·5 lbs., only increased, in their mean magnetical power, to about 5 lbs., or double their former energy,—whilst some of the bars of the smaller magnet (that of five-bars), annealed more fully, had their original power more than trebled.

Subjecting, therefore, these fifteen bars to the final annealing, where the temperature, which rose at a maximum to 505°, was kept up, betwixt that and 500°, for above a quarter of an hour, —the effect, as to the augmentation of the magnetic capacity of the bars, separately, was quite satisfactory. For now each bar, when fully magnetized, was capable of sustaining a tension, as measured by the spring-balance, of from 7 to 9 lbs. (in one instance a tension of 10 lbs. was borne),—the general average being about 7·5 lbs.

These bars, when combined as one magnet, were found to have derived a satisfactory augmentation of energy. The original permanent power of this magnet, when quite hard, was only adequate to the support of about 26 lbs.; but now, after numerous trials, and the repeated breaking of the contact of the conductor, it would readily sustain 45 to 50 lbs.; a weight, which, on one trial, was gradually augmented to 56·6 lbs., before the load fell, being seven times its own weight.*

The loss of power in this magnet, by the combination,—indicated by the difference betwixt the aggregate sustaining powers of the bars separately, and that of the bars combined as one magnet,—was just about one-half: the loss, by combination of the bars, in the five-bar magnet, was about three-eighths.

From the great quantity of power lost by combination in the large magnet, with the disadvantageous effect (apparently) of the last annealing of bar No. 5, Table xxxiv., I inferred that the large magnet had been annealed at a maximum, if not beyond a maximum, temperature, for its best efficiency.

Thus the existence of a remarkable anomaly betwixt the effects of annealing on large combinations of *straight-bar* magnets, and on similar combinations of magnetic bars of the *horse-shoe form*, or, in other words, the existence of this singular difference, that extreme hardness, which is of so decided an advantage in the one case, should have a contrary effect in the other,—seemed to be satisfactorily established.

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* The proportion of load to the weight, carried by the two magnets by Messrs. Stubs, after being annealed, as has been described, shews, I think, that they are *very superior* instruments. My large horse-shoe magnet of nine bars, weighing 22 lbs., will only retain a permanent sustaining power of betwixt three and four times its own weight; and a compound magnet of seven bars, by Dr. Schmidt, weighing 16 lbs., belonging to the Royal Institution, London, which was supposed, I believe, to be a superior instrument, now sustains but 28 lbs., not twice its own weight; originally, however, the sustaining power was, no doubt, very much greater, it having been long in use, and by no means carefully treated.

The cautious philosopher, however, it occurred to me, might here question, whether, in the quality or kind of steel made use of in the construction of these horse-shoe magnets, there might not possibly be some peculiarity not belonging to the steel employed in any of the great variety of experiments hitherto made, by which the benefit of extreme hardness, in considerable combinations of, or masses in, straight-bar magnets, had been determined?

A conclusive experiment was undertaken with reference to this question. I ordered from the manufacturers of the horse-shoe magnets (who also were the manufacturers of the steel of which they were composed), five straight bars, similar in all respects, except as to form, to those of the five-bar horse-shoe magnet. Fortunately I was enabled to procure them *exactly as I required*,—of the same quality of steel as that out of which the other magnets had been made, cut off a bar of the same size, rolled out of the same ingot, and hardened by the same workman, precisely in the same manner. Each of them measured twelve inches long, one inch broad, and three-sixteenths thick. These straight bars, not being polished, were a little heavier than the others,—the total weight of the five being 3·164 lbs., instead of 2·914 lbs., and the difference of the weight of the bars, separately, about 250 grains.

These five straight bars, whilst in their condition of extreme hardness, were magnetized by the pair of 15 inch busk-magnets of 192 plates, so as to have the maximum power developed of which they were susceptible. Tried separately, their action on the compass, at two lengths distance, produced a mean deviation of 17° 40′; and their total powers, when in combination, a deviation of 35° 42′.

These bars were then subjected to the annealing process, at a temperature of 505°, and kept about that temperature for 15 or 20 minutes. Their powers, when again magnetized, were found, exactly as had been expected, to be *increased* when tried *separately*, but *diminished* when tried in *combination*: their separate deviations being now, on an average, 19° 9′, and their united influence 34° 22′. The effect of the testing, on their respective powers after the combination, was not quite so conclusive, there being an *apparent* gain, on the average, of about two per cent. But, then, the test was not in both cases the same; the testing being the effect only of the united powers of the set of bars, which, in the latter case, being weaker than in the former, might occasion the small apparent discrepancy in this quality of the bars in their two conditions of hardness.

Still, in regard to the real object of inquiry, the experiments with the five straight bars, in their two conditions of hardness, H and A, were, I conceive, quite conclusive. For they were in strict accordance with the law so often demonstrated in this work,—that extreme hardness, in considerable combinations of magnetic plates or bars, is the most favourable condition for the obtaining of the highest degree of energy.

Hence this important result, as to the reality of the foregoing conclusion, of a certain change in the form of a magnet occasioning a complete reversion of the conditions requisite for the highest energy, is obtained. For comparing the results of these two series of experiments, in which combinations of magnets were employed in all respects the same, except as to form,—we arrive at the conclusion sought to be established: viz., That the extreme hardness which contributed to the maximum power of the combination of magnets in the straight-bar form, detracted from the power of a corresponding combination in the horse-shoe form; and that the same degree of annealing which doubled the power of the series in the latter form, actually diminished the energy of the series in the other form.

The investigations of this and the two preceding chapters, as a whole, go far towards the satisfactory determination of the important inquiry proposed at the outset of chapter v.—as to the best quality, denomination and temper of steel, for each of the different limited masses or combinations, requisite to be employed in the construction of directing magnets for sea-compasses? They likewise yield results, of a very conclusive description, which are applicable to magnetic instruments and apparatus generally. But, it will be observed, that the general conclusions are of a conditional, rather than of a positive, character. For the results now, as well as heretofore, obtained, are demonstrative of the fact, that no *general* or *universal answer can be given to the question—What is the best denomination of steel*, or *what is the best temper or degree of hardness for magnetical purposes?* For denomination, and mass, and hardness, and form, are, severally, qualities of varying influence in their magnetical relations—changing the comparative resultant energy, as we have already seen, with the changes in these qualities, according to the peculiar laws of magnetism, and their mutual influences, belonging to each of these conditions respectively.

Thus each case, of a number, where there are differences in quality or denomination of the steel, of mass or extent of combination, of hardness or of form,—becomes, in certain measure, a special case. But we have now attained to such an extent of information on these various influencing qualities, and on the mode in which they severally and unitedly operate on the magnetical powers of bars or plates of steel, whether single or compound,—as to be enabled, on the statement of any particular requirement, to determine with much satisfactoriness and practical facility, what the best denomination and quality of steel, and what the best degree of hardness, for such a magnet, actually are. For the various propositions, derivable from the foregoing investigations, which are here thrown into the usual form of General Results—will be found, I expect, to comprise the great majority of cases likely to occur in Practical Magnetics; whilst principles will be found developed, I hope, calculated to afford, by close analogy, some useful measure of guidance in all. In these Results, I may add, will be found embodied certain additional facts derived from the experiments of this chapter, which do not altogether appear in the printed tables.

RESULTS.

The three preceding chapters, IV. V. and VI., comprise the examination of the magnetical properties of a considerable variety of specimens of steel of various qualities, of different denominations, and in the several conditions betwixt that of extreme hardness (H), and that produced by annealing in boiling linseed oil (AB). The measure and kind of knowledge hereby acquired, in respect to the phenomena of magnetism in plates and bars of steel, will be the most conveniently epitomised, compared and illustrated, in our usual method of results. Some of these investigations, indeed, are, in substance, similar to others already described; but not in all the circumstances connected with the experiments. For in each case, whether entirely new, or in a great measure corresponding with what has gone before, there will be found certain differences, the knowledge of the effects of which was requisite, in order to the determination of the nature and measure of importance of all the circumstances affecting the magnetic energy in permanent artificial magnets.

To facilitate the comparison of the effects of *denomination* and *quality* on the capacity for, and tenaciousness of, the magnetic condition in HARD STEEL [temper H], I here prefix a table comprising a new investigation made with a selection out of the foregoing varieties of steel, comprising all the more characteristic differences, with the comparative degrees of the retentiveness, as determined *by an uniform testing* of all the plates under the same exact measure of violence. Column I. will readily shew to what set of plates, and column II. to what class, each of the different plates belongs.

Table XXXV.—General Results concerning the Effects of *Denomination* and *Quality* on the capacity for, and tenaciousness of, the Magnetic Condition in straight Bars and Plates of Hard Steel,—Temper H.

Set of Plates.	Class of Steel Plates.	Weight in Grains.	Maximum Power.		After Testing under Power of 50° 40′.	
			Deviation.	Tangent.	Deviation.	Tangent.
I.	II.	III.	IV.	V.	VI.	VII.
			° ′		° ′	
I.	*CS.*	986	22·30	414	18·45	339
—	—	—	21·4	385	18·24	333
X.	*C. cf.*	943	25·28	476	0·15	4
—	—	—	25·12	471	0·48	14
VIII.	*C. b.*	979	27·25	519	17·23	313
—	—	—	27·12	514	14·22	256
V.	*CL.*	952	20·37	376	18·0	325
—	—	—	21·42	399	18·40	338
IV.	*CS.*	607	11·25	202	8·0	141
—	—	—	12·0	213	9·10	161
*	*C.*	700	12·50	228	10·44	190
*		—	15·5	270	12·38	224
XXV.	*CM.*	394	7·50	138	6·22	112
—	—	—	8·50	155	7·22	129
II.	*SS.*	890	23·37	437	13·13	235
—	—	—	21·15	389	13·0	231
III.	*SS.*	632	16·38	299	2·5	36
—	—	638	17·20	312	2·12	38
* *	*B. cf.*	640	16·26	295	12·38	224
* *	—	—	15·58	286	12·30	222

The Plates marked * column I. were from an undescribed quality of Cast Steel. Those marked ** of Blister Steel from commonest Foreign Iron.

The various results, derivable from the investigations of the three preceding chapters, may, with respect to *straight bars* and plates, be conveniently arranged under five classes; besides the *peculiar* results as to magnets of the horseshoe form. And it will be important to observe, that the results belong to the particular dimensions and masses of steel herein employed (the length being uniformly 7·5 inches or 6 inches), or to combinations of plates of like sizes. For facility of description and reference, I may distinguish three classes, as to mass or thickness:—*thin* plates, such as those designed for compound compass-needles, being of the description employed in Tables XIII. to XXV.;—*medium* plates, such as those employed in the investigations of chapter IV.;—and *thick* plates or bars, being of a mass greater than the preceding. In 7·5 inch plates, the *thin* kind would extend up to about 500 grains weight; the *medium* from 500 to 1500; and the *thick* from 1500 grains upwards. In 6 inch plates about half these weights.

Were more accuracy needful, the proportion which the area of the end, or transverse section, of a bar, bears to the superficial area of the four sides, might afford a mode of discriminating, proportionally, the relative masses, whatever might be their lengths.

SECT. I.—*Results in respect to Difference of* DENOMINATION *in the* SAME QUALITY *of Hard Steel.*

In speaking of *hard steel* (H), or of "*steel quite hard*," it should be understood, that the highest degree of hardness produced by immersion, at a bright red heat, into a saturated solution of salt and water, is meant. The result of this process on cast-steel corresponds with the hardness of the best files.

1. That the *magnetic capacity* differs in each *denomination* of hard steel, being (as shewn in comparatively small masses) the lowest in denominations susceptible of the greatest hardness.

By *magnetic capacity,* I here mean the measure of energy which any bar or plate is capable of *receiving*. Thin or medium bars or plates exhibit their relative capacities, in a considerable degree, by their sustaining as well as their recipient capabilities.

The capability of sustaining the tension of a high degree of magnetic energy, it has been already shewn, exists, in the case of large masses, under different conditions from those of this result,—where the ultimate energy in denominations of the lowest capacity for magnetism becomes the greatest, by virtue, not of the capacity, but of the superiority of such denominations in fixidity.

Within the limits, however, of the masses investigated in the three preceding chapters, the proposition above stated is generally borne out: in the case of the thinner plates the result is always found consistent.

2. That in thin and medium plates made *quite hard*, shear steel possesses a higher capa-

city, and exhibits a greater energy in the *individual plates*, than blister or cast steel, and cast steel the least of all.

In the comparison of hard *thin* plates, such as those of six inches in length of 100 to 200 grains weight, or of 7·5 inches of about 400 grains,—we find this result constantly maintained. Thus, in regard to the powers of *thin* 6 inch plates, of best quality, we find these mean results:

				° ′
xvii.	*Cast steel*, weight,	123	grains; mean power,	5·40
xix.	*Shear steel*, "	119	" "	7·40

And in 7·5 inch plates we find:—

xxii.	*Cast steel*, "	427	" "	10·7
xxv.	*Mint steel* (cast)	393	" "	8·52
xxiii.	*Shear steel*, "	400	" "	12·44

In the comparison of *medium* plates—such as those of 7·5 inches in length, weighing 800 to 1000 grains—we find the powers of the different denominations still supporting, though in a very inferior degree, the above proposition:—

				° ′
Table i.	*Cast steel*,	986	grains; mean power	20·20
ii.	*Double shear*,	890	" "	22·45
Again, v.	Cast steel,	952	" "	20·27
vii.	Blister steel,	982	" "	22·6

The curves belonging to these three denominations of steel, as represented in diagram No. 5, shew, that the superiority of hard shear-steel over hard cast-steel continues to a much larger extent of mass or combination than 1000 grains, or of that of any one of the plates which I employed.

3. That the comparative magnetic powers of different denominations of steel change their relation to each other *in combination*; each deno-

mination, under powerful combinations, exhibiting a degree of effectiveness according (apparently) to its susceptibility for *hardness*.

Thus we find that *shear* steel, which exhibits a much higher capacity for magnetism in thin or medium plates than *cast* steel, is very inferior when a number of plates are combined together as one magnet.

In the case of Messrs. Stubs' peculiar steel,—Tables I. and II. shew these differences very satisfactorily, betwixt the powers of cast and shear steel in combination.

Six plates of *cast steel,* of 986 grains each, exhibited in combination a deviating power of 53° 44′; whilst six plates of *double shear*, of higher magnetic capacity in the separate plates, had a power only of 49° 0′.

Again:—Six plates of *cast steel* (Tables V. VI. VII.) from hoop-L iron, of 952 grains weight each, evinced a power in combination of 55° 30′ in one set, and of 54° 20′ in another; whilst six plates of *blister steel,* of 982 grains each, exhibited a united deviating action of 51° 23′.

Referring to diagram No. 5, we observe that the advantage of the best double shear-steel over the best cast-steel, when both are *quite hard,* continues up to the combination of about three medium plates, or near 3000 grains weight in the total mass. Beyond this measure of combination, the cast-steel, from hoop-L iron, assumes its characteristic superiority.

That the difference betwixt the powers in combination of the cast and shear steel is mainly to be ascribed to their unequal indurative capabilities, seems strikingly to be indicated by their respective deterioration in the individual energy of the plates, by the effect of the same degree of tension or violence to which both qualities had been subjected. Both sets of plates had been subjected to a magnetic power indicated by 50° 40′ of deviation (Table XXXV.); but this degree of violence, which had reduced the *cast*-steel plates (set I.) on an average from 21° 47′ to 18° 35′, produced in the plates of double shear-steel (set II.) a reduction of power from 22° 26′ to 13° 6′. Tested under a tension of 71° 47′, the same denominations fell in still greater proportions; the cast steel on an average from 20° 20′ to 12° 6′, and the shear steel from 22° 45′ to 4° 58′ (p. 190).

In respect to the apparent difference of hardness of shear steel and cast steel, when both are hardened to the utmost, it must be admitted that the conclusion is derived rather from analogy, with reference to their respective magnetical properties, than from direct experiment. It is possible, therefore, that the magnetical differences may be owing to some other cause.

4. That *cast steel*, being capable (as it would seem) of the greatest hardness, is, as a denomination, the most effective in large straight-bar magnets, whether consisting of single massive bars, or of considerable combinations of plates or bars.

A general inspection of the Tables in the three foregoing chapters, and of the diagrams Nos. 5 and 6, will satisfactorily support this proposition as to the relative efficiency of cast and shear steel. The comparative efficiency of *blister* steel has not been sufficiently investigated, though so far as the trial of one set of plates may be relied on, its relative powers have been projected in the diagram No. 5.

It must be kept in mind, however, that we here speak of the comparison of steels made from the highest qualities and of the same description of foreign iron, for it will be seen that cast steel from English iron possesses, apparently, very inferior capabilities for hardness.

SECT. II. — *Results in respect to Difference of* QUALITY *in the same* DENOMINATION *of hard Steel.*

5. That the magnetical properties of the *same denomination* of steel vary with the qualities of the iron out of which the steel may be manufactured.

This general proposition has been discussed in Part I. of this work, and constitutes the foundation principle on which the *quality* of steel is proposed to be determined by the magnetical test.

6. That in *cast steel* from various kinds of iron, the steel from those of highest repute in commerce, so far as yet tried, exhibit generally the best magnetical properties.

This result again corresponds with the views already submitted; and so far as my experiments have yet proceeded, have been satisfactorily verified. One exception indeed, as to the value in the market of a particular "mark" of foreign steel, has been met with, but I have great reason to believe that that description of foreign iron is by no means duly estimated. It bears at present but a low price in the market, whilst it appears to possess first-rate qualities.

The general inference deducible from this proposition is, that the purest iron smelted with charcoal, is the most valuable for the manufacture of steel.

7. That cast steel, quite hard, from the first qualities of foreign iron, appears to be the best for magnetical purposes, where straight bars are employed, and where considerable energy is required; but that for single thin or medium plates, the cast steel from Bradford iron exhibits first-rate capabilities.

This result is drawn from the experiments given in Tables I., V., and VIII. to XII. Taking the *combination* of each set of steel plates to the extent of six, we find that cast steel from the *commonest* foreign iron exhibited a total power only of 37° 15′ deviation in one case [Table X.], and of still less, (28° 42′), in another trial of the same plates after re-hardening [Table XI.] Cast steel, again, from a *good* quality of foreign iron, yielded, in six plates, a power of 49° 37′. The same denomination of steel from Bradford iron gave a power, in six plates, originally of 48° 40′ [Table VIII.], and after re-hardening of 50° 0′; whilst the cast steel from best Swedish hoop-L iron sustained the magnetic energy in six plates to the extent of occasioning a deviation in the compass-needle at two lengths distance of 55° 30′ in one set [Table V.], and of 54° 20′ in another set [Table VI.] The power yielded by Messrs. Stubs' peculiar steel was somewhat lower, being 53° 44′ [Table I.] The small differences in the weight of the plates have not been taken into account in these comparisons, not being considered important; but in the diagram No. 5, the cast steel from hoop-L iron and that from Bradford iron are fully compared.

In regard to *single plates* of thin or medium masses, the steel from Bradford iron exhibits, as shewn both in the Tables VIII. and IX., and in the diagram No. 5, an observable superiority, which superiority is maintained up to the extent of a combination of about three plates, comprising a mass of 3000 grains or upward.

SECT. III.—*Results as to the Changes in Magnetic Properties produced in hard Steel (straight-bar or ruler form), of different Denominations and Qualities, by* ANNEALING (AB.); *that is, reducing the hardness, by subjecting the Plates to the heat of* BOILING *Linseed Oil.*

Some of the results under this head may appear to have been anticipated, in substance, by those at the end of chapter III.; but as the present deductions refer to a specific degree of reduction of hardness on various kinds of steel, their omission would have rendered the series of investigations incomplete.

8. That the *annealing* of hard steel plates or bars (being the same thing, in effect, as tempering), changes the relative positions of the different denominations of steel as to their magnetical properties.

The slightest examination of Tables XXVII. and XXVIII. will be sufficient to establish this proposition; whilst the inspection of diagram No. 6, will shew the progress of the magnetic changes produced by annealing, in the degree now under consideration, in two denominations of steel, *cast* and *shear*, under the action of successive additions of magnetized plates in combination.

9. That, in the case of *thin* plates, each kind and denomination of steel *gains* power, in the

individual capacity of *hard plates*, by annealing in boiling oil; whilst *medium* or *thick* plates, or combinations of plates, generally suffer loss by the same extent of reduction of temper.

The *thin* plates experimented on, consisted of 6 inch plates of 119 to 242 grains in weight, and of 7·5 inch plates of 394 to 590 grains. In every kind, amounting to nine varieties either of quality or denomination, the annealing of the plates occasioned an augmentation in the capacity for magnetism; the greatest augmentation being in the denomination of cast steel. See Tables XXVII. and XXVIII.

In the case of *medium* plates, however, such as those of 7·5 inches, weighing 900 to 1000 grains, a *loss* of power was occasioned by such annealing of the hard plates in every one, out of six in number, whereon the trial was first made. The extent of loss varied, in the different kinds of steel, from about 2° to 10°.—Table XXVIII.

In subsequent experiments on the annealing of *cast-steel* medium plates, one example of gain occurred to the extent of 3° 34′ deviation.

When the effect of annealing was examined on larger masses—such as a combination of those of *medium*, or even of the *thinner* plates—the loss of power by the reduction of hardness was still more striking. Thus *two* plates of 1005 grains each (cast steel from Bradford iron), were reduced in their combined deviating energy from 38° 45′ to 20° 20′, by being annealed. Table XXVIII.—So also, in the case of the thin 6 inch plates, set No. XIX., four plates of shear steel, in combination, had their powers reduced by annealing from 23° 20′ to 18° 40′.

10. That in *thin* single plates, *shear* steel gains *slightly* and *cast* steel *greatly*, by annealing in boiling oil; whilst in considerable combinations of plates, *shear* steel suffers much more deterioration in its magnetical powers than cast steel.

The proportional *gain* of cast steel over shear steel, in single plates, by *annealing*, is shewn in Table XXVII. Cast steel, in thin 6 inch plates, is there found to gain about 60 per cent., and in thin 7·5 inch plates about 60, separately; whilst shear steel of like dimensions, only gains about 24, and 10 per cent. in the separate plates. In *pairs* of plates, similar cast steel plates of 6 inches (being less in mass, proportionally, than the 7·5 inch plates), gain 40 to 50 per cent. by annealing, and the 7·5 inch plates 25 to 35 per cent.: whilst shear steel plates in pairs of like dimensions gain but from 1 to 15 per cent. in the 6 inch plates of 119 grains, and actually *lose* from 10 to 15 per cent. by annealing in the 7·5 inch plates of 400 grains.—Table XXVII.

In larger combinations than that of pairs—the cast steel continues to exhibit an advantage by annealing, up to a combination of about 7 to 8 plates; the curves crossing, in the case of the 7·5 inch plates, betwixt the seventh and eighth plate. In the shear steel, the curves, it will be observed, cross a little beyond the first plate.—Diagram No. 6.

11. That the superiority of shear steel over cast steel, as exhibited in the comparative capacity of the two kinds, in thin or medium plates, hardened in a similar way, is apparently owing

to its inferior hardness, which, in such small masses, is favourable to capacity; but when the cast steel is reduced by annealing, or tempering, to a similar measure of tenaciousness of the magnetic condition, or correspondency of hardness, (?) then the apparent superiority of the shear steel mainly disappears.

In this proposition, the results given in Nos. 2, 4, and some others, are generalized, and the effect of annealing on cast steel added thereto.

12. That in the process of annealing, no difference is found in the resulting magnetic capacity of steel plates, whether, after being subjected to the heat of boiling linseed oil, they are cooled suddenly or slowly.

For the determination of this fact, which might have been of much practical importance, a variety of experiments made on two different occasions were instituted, which are briefly described in the text of the foregoing chapters; the results have been reserved for this place.

In this investigation double sets of *thin* and *medium* plates were employed, some of 6 and others of 7·5 inches in length. On the first trial these consisted of six varieties, and on the second of nine varieties, of the plates previously made use of in the experiments referred to in the tables of the last three chapters. A careful examination of Table XXVII., in which is registered the first series of experiments, will verify, I think very satisfactorily, the above proposition.

The powers of each set in pairs, when compared after being annealed, shew, indeed, a very slight inferiority in the plates cooled slowly (col. IX., Table XXVII.): but on comparing the resulting powers, after application to the test-bar (col. X.), we find an equivalent compensation in the superior endurance of the test, in the last four sets of plates. And in the second series of experiments (Table XXVIII.), we find the rule still further confirmed, and the *apparent* objection just noticed further weakened, by the fact—that, in a comparison of the sets XXII. and XXIV., those plates which were cooled slowly, after being annealed, exhibited a somewhat larger capacity, both singly and in pairs, than those which were plunged into cold oil.

13. That the *measure of reduction of hardness* which takes place on the annealing of hard steel plates or bars, depends on the degree of heat, not on the method of cooling, to which the steel, during the process, is exposed.

This proposition we obtain, by simple inference, from the illustrative notes under the preceding one.—Whether, however, the degree of reduction in temper, exactly corresponds in plates or bars of different proportional masses, has not been determined. Some very thin plates, indeed, appeared to have lost more of their hardness by the annealing than the others, and more than was due to the degree of heat to which they had been subjected: but in this case the quality of the steel might have been injured in the process of hardening, or the original hardness might have been inferior in these, to that of the other plates with which they were compared.

14. That no essential difference was observed in the effect of the annealing process, whether

the hard steel was immersed in the boiling oil only for a minute or two of time, or for as many hours; provided, only, the steel had become duly heated throughout its substance.

This proposition is founded on the examination of the effects of annealing in sets XVII. XVIII. XXII. and XXIV., as exhibited in the two cases of Tables XXVII. and XXVIII.; and also, in the comparison of sets XXII. and XXIV. in the two sections of Table XXVIII. In the first instance we have the case of the plates being put into very hot oil, and remaining therein nearly two hours, whilst it was gradually advancing to the boiling point, in comparison with the exposure of plates of the same set to the heat only for two minutes, and that whilst the oil was boiling. In the second instance we have similar plates, brought into comparison, when one part or selection had been immersed for thirty minutes, the other only two minutes in the boiling oil.

15. That when *magnetized* plates or bars are subjected to the process of annealing, the effect on their original energy appears to be somewhat deteriorating,—slightly so in the case of best cast steel, and considerably so in the case of shear steel.

The impracticability of keeping the plates and bars free from the influence of each other, when placed in the same vessel, though adjusted generally in pairs with diverse poles in contact, renders this result not very conclusive.

In the case of *cast-steel* plates, of the sets XVII. XVIII. XXII. XXIV., the average loss of power observed on the completion of the process (the power being previously reduced by testing, as shewn in col. VII., Table XXVII.), was about seven per cent. But the shear-steel plates (from sets XIX. and XXIII., Table XXVII.) lost, on an average, about 24·5 per cent. This large amount of loss, however, might probably have been partly occasioned by the deficiency in the property of fixidity in the annealed shear steel, whereby unfavourable contact with the more powerful plates of cast steel would have a highly deteriorating influence.

SECT. IV.—*Effects of* ANNEALING *on the Energy of hard straight-bar or plate Magnets, at degrees of Temperature* INFERIOR *to that of Boiling Oil.*

16. That the annealing of thin and medium plates, whether of *best* cast steel or shear steel, at temperatures not exceeding 400°, seems to produce no material change in their *individual* magnetical capacity; though a sensible deterioration in their tenaciousness of the magnetic condition begins to take place below such temperature.

Comparing the deviations given in columns I. and V. in Tables XXIX. to XXXIII. inclusive, in the experiments on annealing at the three temperatures of 300°, 350°, and 400°, we find only a gain of about 1° 10′ in the whole,—indicating a proportional augmentation, by the annealing of these various plates, not exceeding a two-hundredth part of the original magnetical capacity.

17. That, annealed at temperatures *above* 400°, both medium and thin plates of *best cast-steel,* gain, singly, in magnetical capacity; the thin

plates in an increasing ratio up to the boiling temperature, and the medium plates attaining a maximum, at the temperature of about 500°, but these medium plates falling at the boiling heat so as to approximate the capacity in the original hard state.

It is shewn, in Result No. 9, that medium plates of steel of the various qualities and denominations yet subjected to experiment, generally *lose* by the process of annealing at the boiling temperature. In the case of best cast-steel, however, in 7·5 inch plates of about 1000 grains, the resulting *capacity* for magnetism, after annealing at a boiling heat, does not appear to be materially different from that of the original hard state. In one experiment, Table XXVIII., such a plate suffered a loss of nearly 2° by the annealing; and in another, Table XXX., there was a gain of 3° 34′, in the deviating power, after being subjected to the like treatment.

Cast steel from English iron, or common foreign iron, seems to follow the law of shear steel very nearly, having the highest capacity for magnetism, except in very thin plates, when quite hard.

18. That hard *shear steel,* annealed at temperatures *above* 400°, seems to gain, though very slightly, in capacity, in *single thin* plates, up to the boiling temperature; but loses very considerably in *pairs* of plates at the higher temperatures. In *medium* plates, any reduction of the extreme hardness (unless such as might result from the lowest temperatures) appears to deteriorate their capacity, singly, for magnetism, and very greatly so in combination.

The *gain* of power by annealing in *thin* shear-steel plates, when tried at various temperatures, was only, on an average, 0° 32′ (Table XXXII). The greatest gain, in any one instance, did not exceed 1° 30′, or about 12 per cent. The same *pair* of plates, however, in which this gain in their separate capacity was exhibited, were found to have *lost* a still greater proportion of their united powers, when in combination.

In the case of shear-steel plates, betwixt the thin and medium weights (Table XXIX.), there was a general loss, on the average, in the powers of the single plates, by annealing at all the different temperatures. In a shear-steel medium-plate of 912 grains (Table XXVIII.) the loss by annealing was much more considerable.

19. That the annealing of any plates or bars of a straight or ruler form (designed for magnetical instruments), whatever be their denomination or quality, is always injurious to their *tenaciousness* of the magnetic condition; the deterioration in this quality of the magnet increasing, as the heat is increased, and becoming very injurious to permanency when the temperature is raised to near the boiling heat of oil.

Column VII., in each of the tables of the series commencing with XXIX., shews the progressive deterioration, with the increase of the temperature, in annealing, as proved by the relative effects of the operation of testing. Beyond the heat of 450°, in the case of cast steel, and of 350 in shear steel, it is observable, the influence of the heat becomes very rapidly deteriorating.

20. That the effect of annealing, at all tem-

peratures, on *pairs*, or on *larger combinations*, of *medium* or *thick* plates, is a general disadvantage to the powers of straight-bar magnets of every kind of steel; the disadvantage increasing with the augmentation of the temperature, and the extent of the combination of the plates or bars. On *pairs* of *thin* plates of best cast-steel, the effect, as hereinafter shewn, is different.

A comparison of columns II. and VI. in Tables XXIX. to XXXIII., will be sufficient to verify this proposition. In the semi-medium plates, Tables XXIX. and XXXI., a very small improvement seemed to be produced by the annealing at the lowest temperature; but in the medium plates, Table XXX., an opposite effect took place.

21. That the repetition of the process of annealing on the same plates or bars of originally hard steel (the temperature of the oil being the same or not greater) does not appear to produce any alteration in the magnetical capacity, or any additional reduction of the hardness.

Besides the indications of the truth of this proposition, yielded by the series of investigations described in the annexed chapters, a special experiment was made by the annealing of four different descriptions of plates in boiling oil, a part of which had been previously annealed at the temperatures of 300° to 350°, and another part at 550°. No decided difference in the results, either as to capacity for magnetism, or tenaciousness under the action of the test-bar, was observable.

SECT. V.—*Results on the Magnetical Capacities and Powers of Steel Plates, or Bars, adapted for* SEA-COMPASSES, *both single and compound, whether* HARD, *or whether* ANNEALED *at various Temperatures, with the Effects of spacing the Plates.*

These Results apply specifically to needles of 6 inches and 7·5 inches in length, being in the relation to each other, in proportional masses, of 1 to 2 nearly. In most of them, the results here given are deducible from the propositions previously laid down; but they are here brought together for a more satisfactory determination of the principles affecting the improvement of the mariner's compass.

22. That for *single-bar needles* constructed on the principles heretofore generally in use (hardness or temper of the specific degrees H. T. E. S. being considered), hard cast steel is the most effective whenever the weight of the 6 inch bar exceeds 400 to 500 grains, or the 7·5 inch bar, about 1000 grains; but in cast-steel needles of less weight, the directive energy is improved by tempering or annealing.

This Result is amply maintained, as to 6 inch needles, by the illustrative remarks on the Results 2 and 3 of chapter III. The comparison of the powers of two navy needles, one of them being the best out of nine, with bars of my own of hard cast steel, as shewn at p. 45, strikingly verifies the above proposition, where the navy needles of 510 and 580 grains weight, had a maximum capacity, in deviating energy, of 13° 30′ and 5° 35′ respectively, and those on my own principle, of 560 and 656 grains, a deviating power of 19° 30′ and 22° 20′.

In plates or bars of 7·5 inch, the limit, as to the weight at which a reduced hardness ceases to have superiority over what we may call *file hardness,* seems to be greater than that due to the proportion of mass. Such a deviation from *apparent* analogy, however, will prove, I apprehend, to be resolvable into another similar deviation from supposed general laws. Heretofore, I believe, it has been considered as a law of magnetics, that the powers of magnets of different but proportional dimensions are proportional to their masses respectively; but this, according to experiments belonging to a future place of this work, will be found *not to be the fact.* It will be proved, I doubt not, that proportional magnets have *not* powers correspondent with their masses.

23. That for *single needles*—of the weights or dimensions ordinarily used for sea-compasses—the best conditions for directive energy among the various kinds of HARD STEEL examined, are found in this order:—*cast* steel from Bradford iron; *shear* steel, S S. or of *hoop*-L iron; *blister* steel, *hoop*-L; *cast* steel, *hoop*-L;—the cast steel from Bradford iron being the most energetic.

Any *apparent* discrepancy betwixt this proposition and the statements previously made, will be explained by a due consideration of the masses employed. When very *weighty* needles are required, best cast steel will be found available for its general superiority.

The results obtained from the trial of the cast steel made out of Bradford iron were so favourable, as to render it probable, that, for the purpose here contemplated, this steel should be selected. Before, however, this conclusion—derived only from a single set of plates—could be safely adopted, further experiments would be necessary, in order to ascertain whether the obtaining of steel from Bradford iron of like magnetical properties could be always relied on.

24. That for *single compass-needles* of ordinary sizes and weight, hard cast-steel from Bradford iron, hard shear-steel (hoop-L), and cast steel (hoop-L), slightly reduced by tempering or annealing, possess apparently the *best qualities*, as combining in a very high degree the properties of power and fixidity.

The diagrams Nos. 5 and 6 represent to the eye the general truth of this proposition; and a comparison of the Tables in Chapter IV., shews a superiority for single needles of *medium* thickness (such as 7·5 inch needles of 900 to 1000 grains in weight) in the cast steel from Bradford iron, and, next to that, of hard shear steel.

As, however, the Bradford steel, whilst exhibiting a certain superiority over all the other kinds tried in *medium* plates, and also in *thin* 6 inch plates, fell short of the hard shear steel in one set of *thin* plates of 7·5 inches in length,—the degree of reliance to be placed on this description of steel cannot be considered as satisfactorily determined: but as such uncertainty does not attach to certain steels from foreign iron, *hard shear-steel*, from hoop-L iron, might with confidence be adopted for compass-needles, or cast steel, of like quality, annealed, as described in proposition No. 27.

25. That plates or bars of hard *shear steel*, suitable for compass-needles, whether of the single or compound form, are injured in their magnetical capacities, if of masses *greater* than those of *thin* plates, by annealing in boiling oil; nor is the very small advantage which may be gained in capacity, in the case of *thin single* plates of shear steel, by annealing at any of the temperatures betwixt 400° and 600°, at all adequate, as a compensation, for the loss in fixidity.

This proposition, which is deducible from Result No. 18, and Table XXXII., is here given, because of its importance in the management of shear steel for compass needles. And the conclusion to which it leads is—that, where shear steel is employed in compasses, the original hardening should not be interfered with, except so far as may necessarily take place in the adjustment of the plates into form.

26. That whilst the extent of the reduction of hardness by the annealing of compass needles in *boiling linseed oil*, is generally injurious to the magnetical properties of *shear-steel* plates,—the same measure of reduction is likewise injurious to the energy of *cast-steel* (hoop L), when the total weight exceeds about 400 grains in 6 inch plates, or about 1000 grains in 7·5 inch plates.

The injurious effect of this extent of reduction of the hardness of *shear steel* is strikingly shewn in diagram

No. 6. The powers of a combination of plates of *cast steel*, tempered, (*CL.* T.), and of the same annealed (*CL.* A.), when projected in a diagram not here given, were found extremely similar, almost coincident, in the case of 6 inch plates of about 140 grains each, even up to a weight altogether of about 600 grains. With plates of 7·5 inches long, however, the similarity, though proximate, was not found to be so exact.

It has been shewn in Proposition 17, that *cast-steel* plates, of medium mass, gain power by annealing at temperatures *below* the boiling point of oil.

27. That *thin* plates of *cast steel*, adapted for the needles of compasses, whether employed singly or in pairs, have their magnetical capacities *improved by annealing* at any of the various temperatures betwixt 400° and the boiling heat,—the temperature of boiling yielding the highest capacity in thin single plates, and that of 500° to 550° in pairs of plates.

This result, derived from the experiments of Table XXXIII., will be seen to be of much practical consequence in the construction of the needles of sea-compasses. It determines, and I think satisfactorily, the degree at which the plates for compasses, when made of cast steel, should generally be annealed.

28. That for *compound* needles, say of two *thin* plates in contact, cast steel annealed, *CL.* A., hard shear steel, *SS.* H., or *SL.* H., and hard cast steel from Bradford iron, appear to possess magnetical qualities remarkably similar in fitness.

This proposition relates to 7·5 inch plates of about 400 grains, or 6 inch plates of about 100 to 200 grains in weight. Taking the united weight of the 7·5 inch plates at 800 grains, we find the curves in diagram No. 6, of cast steel annealed, hard Bradford steel, and hard shear steel, nearly coincident.

Comparing again the powers of a pair of 7·5 inch plates for compass needles of different kinds, as shewn in the Tables, we find—

		Grains.	Deviation.
Shear Steel, *SS.* H. (XXIII.)	total weight	800	21° 25′
Bradford Steel, *Cb.* H. (XXVI.)	,,	840	21° 32′
Cast Steel, *CL.* A. (XXVII.)	,,	848	21° 33′

In the case of 6 inch needles in pairs, of *less* weight than 200 grains each (say 100 to 150 grains), the steel from Bradford iron presents some advantage over the other kinds. And *cast* steel annealed at the heat of boiling oil, is very analogous to hard *shear* steel up to a combined weight of about 300 grains; beyond that weight, both hard shear and hard Bradford steel have a decided pre-eminence.

29. That as the employment of two or more plates has always an advantage, in magnetical power, over a like mass in a single bar; so the *separation* or *spacing* of such combined plates is further beneficial to the directive energy of compound compass needles.

This proposition, which is a general conclusion from the previous investigations of chapters I. and VIII., Part I., is here repeated, simply because of its applicability to the particular subject now under investigation: viz. the improvement of sea-compasses.

30. That the quantity of gain by *separation* varies in an augmented ratio, directly with the number of plates combined, and inversely with the degree of hardness.

The first part of this proposition is derived from the investigations of chapter II. The second part is shewn by a comparison of the quantity of gain, by separation, in combinations of tempered plates, [Tables XIII., XIV., and XV.], and some experiments made with hard plates, which have not been described in the body of this work. In the case of *hard* plates, however, the quantity of advantage by spacing was found to be considerably less—and that for the obvious reason, that as there is less loss on the combination of hard plates or bars, than on those that are tempered, so the gain, by attenuating the intensity of the energy in hard magnets, must necessarily be less.

31. That the spacing of thin plates for compass needles of hard shear steel, or slightly annealed cast steel, whether combined in sets of two or four, affords an augmentation of very sensible importance in the directive energy; but in the case of hard cast steel the quantity of gain is not considerable.

In the case of *tempered* plates [*C.* T.] we find an average gain in directive power of about 5 per cent. by the moderate spacing of two very thin plates, and of about 15 per cent. in the spacing of four such plates. Tables XIII., XIV. The tempered plates of 7·5 inches, and about 231 grains weight each, Table XV., were found susceptible, in a combination of four plates, of a greater power when separated by discs of about one-eighth of an inch thick, than when in contact, in the ratio of the tangents of deviation of 25° 22′ to 21° 12′. And two *annealed* plates, *C.* A., of 427 grains each, spaced for a compass needle, received a power of 26° 40′, which, in contact, was reduced to 22° 46.

But the power of four 6 inch hard cast-steel plates of 123 grains weight each, which in close combination produced, when fully magnetized, a deviation of 19° 45′ on the compass, was increased only to 20° by separating the plates into two pairs, about a quarter of an inch asunder. In like manner four other hard cast-steel plates of 136 grains, were found to obtain an increase in power only from 18° 20′ to 18° 50′, scarcely 3 per cent., by a similar separation. Hard *shear-steel* plates, however, in accordance with general analogy, gained considerably more by the separation.

Hence, in the employment of *very hard plates*, in so exceedingly limited a combination, the advantage of total separation is found to be so inconsiderable as to render it of little practical consequence whether the plates, separated in the middle, are united at the extremities, or kept separate throughout their length.

The further consideration of this subject, which may justly be held, I conceive, to be of national importance—involving as it does, the safety of the lives and property depending on the guidance of the compass—is reserved for the practical application of the principles, thus far determined, in a subsequent part of this work.

The best form, or forms, for the compass needle, will then also fall under consideration; when the disadvantages of the ordinary kind of single-bar needle will be seen, and the variety of forms, with their respective advantages, in which the needles of the compound kind may be conveniently constructed, will be described.

SECT. VI.—*Results in respect to the peculiar effects of hardness and annealing on Magnets of the* HORSE-SHOE *form.*

32. That whilst denomination and quality, degree of hardness and measure of combination or mass, are, severally, qualities of varying influence in their magnetical relations, changing the comparative resultant energy with the changes in these qualities respectively—so the *form* of the magnet (as to straight-bar, or horse-shoe) has likewise its peculiar effect in again influencing the results of hardness, and measure of combination.

This fact is the general conclusion from the investigations of sect. III. of chapter VI.,—a result, however, which could scarcely have been anticipated from any known analogies.

33. That the conditions requisite for highest energy in large masses, or powerful combinations, in magnets of the *straight-bar form*, are,

as respects the influence of extreme hardness, totally different in the case of magnets of the *horse-shoe form.*

The large combination of hard bars of the horse-shoe form—to the extent of fifteen in number (p. 238)—indicated, in its unexpected feebleness when magnetized and put together, the existence of this peculiar law.

34. That the *extreme hardness* which contributes to the maximum power of considerable combinations of, or masses in, magnets of the straight-bar form, is injurious to the power of a like combination of magnets of the horse-shoe form; and that the annealing or tempering which detracts from the united energy of the straight-bar series, improves the power of the horse-shoe series.

The last experiment described in sect. III. chap. VI., is, I think, quite demonstrative of the truth of this proposition: for in that instance the comparison was made by the use of bars in all respects exactly the same, except as to form,—yet the results, as to their magnetical powers, were totally different. The *extent* of combination to which this law applies, has not been determined.

35. That whilst a given measure of hardness throughout improves the sustaining power of compound magnets of the horse-shoe form; the improvement, in the case of cast steel, attains to a maximum considerably below the condition of extreme hardness.

The hardening of the bars of a large horse-shoe magnet up to a certain degree—about that perhaps of spring temper, except at the curve, which was still left soft—produced, as has been shewn at page 173, a very great improvement in the energy of the entire magnet; but the hardening of a 15 bar magnet, up to the state of files, as has also been shewn, was very disadvantageous to the power of that instrument.

36. That, for cast-steel magnets of the horse-shoe form, and in masses of the ordinary dimensions, the effect of annealing, on hard bars, is extremely beneficial, both to the energy of the bars separately and in combination,—the most beneficial temperature, apparently, being for single bars about 550°, and for bars designed for powerful combinations from 480° to 500°.

It has been shewn already, that the effect of annealing at the temperature of 500° on the average sustaining power, separately, of the bars of two horse-shoe magnets of hard cast steel constructed by Messrs. Stubs, was nearly to treble their original capacity; and that, in combinations of 5 bars and 15 bars, the effect of the same annealing at the same heat was to double their respective powers.

37. That *hard shear steel*, not reduced by tempering, is admirably adapted for the formation of magnets of the horse shoe form—yielding, especially in compound magnets, very superior powers.

This result, which from the foregoing facts was fully anticipated, was, so far as a single trial may be relied on, most satisfactorily determined. For this trial I obtained from Messrs. Stubs, a five-bar magnet of best shear steel, made quite hard, of very beautiful workmanship. Each bar is an inch broad, 0·35 inch thick, and 7·75 inches long, from the extremity of the curved part to that constituting the poles. The total weight is about 9 lbs. The polar extremity is finished quite square—all the bars being of the same length. The conductor presents a surface to the magnet of 2.25 inches by 0·6 inch, and weighs 2300 grains. Each bar, when fully magnetised, sustained an average tension of 10·75 lbs. And when the instrument was put together, it was found to support a load of 58 lbs. before the conductor separated. A larger portion of this great power was retained than I had found in any other instance,—for, on repeated trials, made at various periods, a load of from 50 to 53 was regularly sustained.

The great variety of propositions into which the foregoing Investigations have become resolved, will be sufficient to justify a preceding statement, that no universal answer can possibly be given to the question—What is the best kind of steel, and the best degree of hardness, or mode of tempering, for magnetical instruments? At the same time, we may derive out of these numerous results, and the variety of specific cases to which they apply, a useful summary for the guidance of the practical magnetician in the leading objects of common requirement.

Thus, to speak in general terms, we should recommend for all *large* or *massive* SINGLE MAGNETS of the straight-bar form—the best *cast steel*, made quite hard: for STRAIGHT-BAR COMPOUND MAGNETS, generally, the same steel and hardness: for compound magnets of my BUSK-PLATE description, the best cast steel, hardened to the utmost in oil: for HORSE-SHOE MAGNETS, if *single*, cast steel annealed from file hardness, at a temperature of about 550°, or shear steel a little reduced; and for COMPOUND HORSE-SHOE magnets, cast steel annealed at 480° to 500°, or shear steel perfectly hard: for COMPASS NEEDLES, if *single* and *heavy*, (such as are suited for stormy weather), hard cast steel; if *light*, or of *moderate weight*, whether single or compound, best cast steel, annealed at 500° or 550°, or hard shear steel, or hard cast steel from Bradford iron: and for VERY LIGHT NEEDLES or other small magnets, the best cast steel annealed, as with advantage it may be, at the heat of boiling oil.

In all these cases, the steel, whatever be the denomination, should be the produce of the best qualities of foreign iron, except in the instance of cast steel for compass needles of a light description, where steel from the best Bradford iron might, it appears, be advantageously employed.

CHAPTER VII.

ON THE POWERS OF HARD STEEL BARS COMBINED IN VARIOUS WAYS, AS ALSO IN PROPORTIONAL MASSES, SO AS TO FORM COMPOUND MAGNETS OF LARGE DIMENSIONS AND OF GREATER LENGTHS THAN THOSE OF THE ORIGINAL ELEMENTARY BARS; WITH A PRELIMINARY INVESTIGATION CONCERNING THE METHODS OF DETERMINING THE RELATIVE POWERS OF MAGNETS OF DIFFERENT LENGTHS.

THE great advance of magnetical science within the present century, and the surprising results of galvanic action, in the development of magnetic energy in common iron, have led to applications of these results, for practical objects, at once beautiful and useful. And as the present state of magnetical science holds out the prospect of still further applications of this wonderful agency, and, *possibly*, the *useful* employment of the magnet as a moving power; the augmentation of the powers of permanent magnets becomes a desideratum of obvious importance.

In magnets of soft iron, whose energies are excited galvanically, or by means of chemical forces—there appears to be no definable limit to their powers. But as for practical and economical purposes, generally, the waste of materials and employment of acids become at once inconvenient and expensive,—there might be an essential advantage if *permanent magnets* could be obtained of very high degrees of energy.

To this consideration my attention was now, in a particular form of inquiry, directed.

In all the foregoing investigations, on the powers of *combinations* of magnetised steel plates or bars, only one general mode of combination had been examined; viz. that of a pile, or fasciculus of corresponding pieces. This mode of construction, however, on account of the practical difficulties in the hardening of very large masses of steel, or in making very long bars quite hard and at the same time keeping them fair and in the required form—is not capable of an indefinite enlargement. Hence I proceeded to inquire into the practicability of combining, to a great extent, comparatively small and manageable bars.

This principle of construction for compound magnets of great power, has, indeed, been long since tried, and, to some extent, successfully. But no investigation, that I am aware of, has been made of the actual powers of a mass of small magnets so combined, compared with those of a corresponding solid mass; nor of the proportional powers of magnets of different lengths, made up of a single line of similar integrant bars; nor of the proportional power of several bars, combined in various ways and in greater lengths, and the same laid together in a single pile, or fasciculus; nor of the relation of the ultimate powers of compound magnets of similar masses, form, and dimensions, when constructed of bars of different lengths; nor of the relative powers of various combinations of bars of the same description (except as to the length of the integrant bars) in proportional masses; nor as to the possible extent, as to mass, to which such combinations may be usefully carried.

These several particulars, however, were required, in the investigation herein contemplated, to be examined, in order to the effectual application of the results to the construction of magnets of extraordinary magnitude and power.

In order to compare the relative powers of various masses of magnetised steel, or fasciculæ of magnets, however, accurately with each other, when their lengths should be different,—some mode of determining their respective powers, of approved accuracy, would require to be employed.

That the method of deviations, herein generally adopted, is, in itself, at once very convenient in practice, and, if corrected, in the case of considerable angles, for the equations mentioned in Part I. chap. III. accurate,—has, in its application to magnets of *corresponding lengths*, been already shewn. It has also been stated (page 21) that for bars not equal as to length, their deflecting energy, if ascertained at distances proportionate to their lengths, will generally give results of useful approximation.

The *measure* of approximation to the truth of the method of deviations, for the comparing of the powers of magnets of different lengths, was of importance to be ascertained, in order that a method so extremely ready and effective might be employed in the immediate object of inquiry. The principle of the method, indeed, led me to expect that, provided the deviations could be taken at such a distance from the compass that the angular direction of the forces of the several magnets to be compared, acting on the poles of the compass-needle, should not be very greatly different,—the method of deviations would, though uncorrected, be equally satisfactory for the determination of the relative powers of magnets of *different* lengths, as it has been proved to be susceptible for magnets of various powers of the *same* length. And in this expectation, I was not disappointed.

The most unexceptionable way of determining this point seemed to be by comparing the method of *deviations* with that of *torsion.* For this purpose, I constructed a " balance of torsion," (on the principle originally introduced by Mr. Mitchell, and employed with so much success by M. Coulomb,) of a large size.

The apparatus was made strong and firm, so as to be capable of testing the power of bars of two feet in length and of many pounds weight. The wire employed for this investigation, (except in the first case, which was thinner) was thirty-six inches in length, and about one-sixty-fifth of an inch in thickness. It was obtained of an admirably elastic kind, by the adoption of a hard-drawn wire made expressly for springs used in the Jacquard Loom. A lantern-case for protecting the magnets from the action of the air, with sliding glasses at the upper side and at one of the ends, was provided of sufficient dimensions for the reception of the two-feet bars. To the lower extremity of the torsion-wire was attached a spring stirrup of considerable breadth, calculated to embrace the bars to be tested very firmly, and to secure their perfect parallelism with the line of Zero of the instrument. A simple mode was also adopted for loading the lighter magnets, so that the quantity of torsion might be always determined under similar circumstances as to the load on the wire. A variety of minor contrivances were adopted for facilitating the repetition of experiments, and securing accuracy in the comparison of magnets of different sizes and masses.

With this effective and satisfactory apparatus, I proceeded to the comparison of the methods of *Torsion* and of *Deviations*, by employing them severally in experiments on the relative Directive powers of Bar magnets of different masses, lengths, and degrees of energy—with the view of applying the method of deviations thus experimentally adjusted and verified, to the inquiry specially contemplated in this chapter. The leading inquiry, however, being conveniently extended into *three Cases*, each having an important bearing on the satisfactoriness of these magnetical investigations generally,—I have thought it desirable to describe them all in this place.

Case I.—*Comparison of the Powers of various Bar-magnets of the same length (viz. six inches), as determined by the methods of Torsion and of Deviations, in order to the further verification of the method of Deviations.*

The applicability of the method of deviations for the accurate determination of the directive powers of different magnets of *equal* lengths, has been shewn in Part I. chapter III. As, however, the soundness, in science, of this very convenient mode of trial, has been questioned,—the verification of the method by another mode which has met with almost universal approval, will be held, I trust, as quite conclusive.

Eight plates and bars, or combinations of plates, were employed in the experiments on this first case, differing in their powers to the extent of 10 to 1. They comprised the following varieties:—

1. A *pair* of compound bars, each bar consisting of twelve hard cast-steel plates, combined together.

2. The same reduced in energy by one thin magnetic plate interposed in the reverse direction, as to its polarity, betwixt the compound bars.

3. The same further reduced, and in a similar

way, by the interposition of two thin magnetic plates with reversed poles.

4. *One* of the compound bars of twelve plates.

5. A single bar of hard cast steel,—a square prism of half an inch thick.

6. A single hard bar, half an inch broad and one-eighth thick.

7. A single tempered plate, half an inch broad by one-sixteenth thick.

8. A single thin compass-needle, three-eighths of an inch broad.

Comparison of the method of *Torsion,* and that of *Deviations,* for the determination of the relative Directive Powers of Bar-magnets of different masses and degrees of energy, made with a series of six-inch Magnetic Bars, Plates, and Compass-needles.

No. of Magnet.	Weight in Grains.	Powers at 4 Lengths from Compass, or 24 Inches.					Powers by Torsion.	
		Mean Deviation.	Tangent.	Ratio, No.1=100.	Equated Tangent.	Proximate Ratio.	Degrees of Torsion.	Ratio, No.1=100.
I.	II.	III. ° ′	IV.	V.	VI.	VII.	VIII.	IX.
1	4075	17·58	324	100·0	314	100·0	48·0	100·0
2	4075 - 318	14·17	255	78·7	251	80·0	38·4	80·0
3	4075 - 640	13·15	236	72·8	234	74·5	36·2	75·4
4	2040	9·46	172	53·1	171	54·5	26·0	54·1
5	2950	7·22	130	40·1	130	41·4	19·5	40·6
6	658	4·0	70	21·6	70	22·3	10·8	22·5
7	·318	2·59	52	16·1	52	16·6	8·0	16·7
8	145	1·50	32	9·9	32	10·2	5·0	10·4

The analogy of the ratios in columns v. and ix., the ratios deduced directly from the experiments, is sufficiently close to prove the general utility of the method of deviations for the determination of the relative directive powers of magnets of various powers,—the mean difference of the two methods on these eight trials, amounting only to about one-fifty-seventh part of the entire power of each magnet. But, as it will be observed that the whole series of powers, as determined by either method, exhibits differences constantly on the same side (the ratio of column v. being constantly lower than that of column ix.), the application of a small equation to the tangents of the deviations, is here found to be necessary.

This equation (taken very nearly in the proportions indicated in the diagram, in plate ii.) being applied to the tangents of the observed deviations, column iv., we obtain the series of equated tangents, column vi. The proximate ratio by the method of deviations, when thus equated, column vii., agrees so well with that obtained by the method of torsion, as to verify, in the most satisfactory manner, that process for the determination of the powers of bar magnets,—a process on which the results in this work, mainly and essentially depend.

CASE II.—*The Determination, experimentally, in Magnets of different lengths, of the relation of their respective deviating effects (at distances from the Compass proportional to their several lengths) to their* ACTUAL DIRECTIVE *Powers.*

The object of this inquiry was to ascertain, how the deviations produced by magnets of different lengths might be reduced, so as to shew the comparative directive powers, or the actual powers with reference to any given standard. In order to this, the determination of the actual powers by the method of torsion, of a series of magnets producing equal angles of deviation at distances from the compass proportionate to their respective lengths, constituted the simplest case which could be well devised.

For this experiment, three straight-bar magnets were employed, of the lengths of 6, 7·5, and 15 inches, respectively,—being, to each other, in the proportions of 4, 5, 10.

Not being either of proportional masses, or of equal deviating powers when magnetized fully, the lowest energy in the three (7° 17′ deviation) was adopted as the standard, and the magnetisms of the other so reduced and adjusted that, at distances from the compass corresponding with four times their several lengths, their deviating powers became alike, or so nearly alike, that the greatest difference from the mean power was only about 2′.

These bars were then placed in succession in the balance of torsion, when their several directive powers were represented by 19·5, 38·5, and 292,—these numbers being the degrees through which the index of the balance required to be turned and the wire twisted, for producing an equal deviation, viz., 30°, from the direction of the magnetic meridian.

Now the proportional powers, thus obtained, just as was anticipated, are found to approximate nearly the cubes of the lengths of the series of magnets. For whilst the cubes of the lengths constitute the series 1, 2·0, 16·0,—the several observed powers of the magnets, reduced to the like extent, constitute the proximate series 1·013, 2·0, 15·2. The differences in the first and last numbers are accounted for by the fact, that the supposed fifteen-inch bar was found to be somewhat short of the proper length, and the six-inch bar a little longer.

For the further confirmation of the law, thus indicated, — a selection was made from other experiments on a more convenient series of bars of six, twelve, and twenty-four inches in length. These afforded the more simple ratio of 1, 2, 4.

Their deviating powers, indeed, were not equal, being 17° 5′, 14° 15′, and 13° 45′; but, guided by the conclusions of case I., there was no difficulty in reducing the powers of the torsion balance to a common standard, by the application of the principle of simple proportions to the observed torsions. Taking, then, the deviation of the middle bar, 14° 15′ (tangent 254) as the standard, the observed torsions, viz., 9·4, 59, and 476, become, when reduced, 7·7, 59·0, 493·5, constituting the series 1, 7·7, 64·1—being a very close approximation to 1, 8, 64, the series formed by the cubes of the lengths of the three magnets. The differences, indeed, are not greater than what may reasonably be attributed to the neglect of the equation of deviations and the errors of observation.

Hence, it is clear that the deviating power of magnets of different lengths, affords, *in the case of equal*, or very nearly equal, *deviations*, a very practical and accurate mode of determining their magnetic powers respectively,—their powers being, in such case, proportional to the cubes of the lengths of the magnets.

But the case under consideration, as stated in the outset, requires further investigation as to magnets of different lengths having *unequal deviations*. Combining the results, however, of case I., with the above of *equal deviations*, (case II.), the rule becomes general under this simple expression:—

$$P = l^3 t$$

P being the actual directive power of the magnet, t the tangent of the deviation produced at a given distance, proportional to the length of the magnet, from the compass, and l the length of the bar.

The verification of the rule by actual experiment will be abundantly yielded by the descriptions of the next case.

CASE III.—*The Comparative Capacities for Magnetism of equivalent, or similarly proportioned, Bars of Steel of different lengths, as determined both by the method of Deviations and that of Torsion.*

This investigation involved other results. In addition to the object specially proposed for inquiry,—the required confirmation of the rule above stated was looked for. For if the ratios of powers of magnets of different lengths and unequal deviations as yielded by the above formula, should correspond with the ratios by the method of torsion—the rule would derive such confirmation as might be fairly considered to be completely satisfactory.

For the primary investigation, I selected out of my large stock of magnets, five hard cast-steel bars of different magnitudes, and of the respective lengths of thirty-six, twenty-four, twenty-four, fifteen, and twelve inches. Having ascertained the weights of the several bars, I then provided a series of six-inch bars of hard cast steel, of *equivalent masses* and *weights*,—the weight of each larger bar being proportional to that of its six-inch equivalent in the ratio of the cubes of their respective lengths. Thus, the thirty-six-inch bar, being six times larger in each of its dimensions (in length, breadth, and thickness), than its six-inch equivalent, would be heavier than such equivalent in the ratio of $6^3 : 1^3$, or 216 : 1. For the large bar, therefore, which weighed 44,950 grains, the equivalent was a six-inch bar of 209 grains: for that of twenty-four inches of 43,450 grains, one of 679, etc.

The whole of these bars being now magnetized to their utmost capabilities by the processes best adapted for the full development of the magnetic energy of the bars respectively,—their several deviating powers, at four times the length of each bar, were first ascertained, and then their respective powers in the balance of torsion. The various results, with all necessary information respecting the several bars, are exhibited at one view in the annexed Table.

TABLE of EXPERIMENTS for determining the Comparative Capacities for Magnetism of equivalent, or similarly proportioned, Bars of Steel of different Lengths, both by the Method of Deviations and that of Torsion. As the Degrees of Hardness and the Qualities of Steel, however, of the different bars, herein submitted to Comparison, were not always Correspondent, the Results can only be considered as Proximate.

No. of Experiment.	Bars used in the Eperiments.		Equivalent of Bar of 6 Inches.		Comparison of Powers by DEVIATIONS.					Comparison by TORSIONS.			
					Maximum Power of Larger Bars.		Maximum Power of equivalent 6-Inch Bars.		Ratio of Bar to its equivalent of Six Inches.	Torsion of larger Bars.	Torsion of Equivalent Bar of 6 Inches.		Ratio of Capacity of Larger Bar to its equivalent of Six Inches.
	Length in Inches.	Weight in Grains.	Equivalent Weight.	Proportion.	Deviation.	Tangent.	Deviation.	Tangent.			Proportional.	By trial of Six-Inch Bar.	
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
					° ′		° ′						
1	36	44950	209	216:1	7·43	136	13·14	235	1:1·73	[875]	—	—	—
2	24	43450	679	64:1	13·45	245	24·26*	454	1:1·85	476	7·44	13·4*	1:1·8
3	24	20080	314	64:1	9·2	159	17·5*	307	1:1·93	303	4·74	9·3*	1:1·96
4	15	12200	781	15·625:1	21·12	388	28·40	547	1:1·41	177	11·4	16·0	1:1·4
5	12	2670	334	8:1	14·15	254	18·47	340	1:1·34	59	7·4	9·5*	1:1·29

The numbers marked with an asterisk, have been slightly altered, to adjust them, proximately and proportionally, to small differences betwixt the actual mass of the six-inch bar employed for the comparison, and the proportional mass, as shewn in column III., "of equivalent weights." The bar used in experiment No. 3, it should be observed, was of a clearly inferior quality of steel to that of its equivalent,—hence the undue difference in the proportional capacity of the two bars compared.

Various results of much interest and importance are derivable from this set of experiments.

1. Taking the method of Torsion as yielding unquestionately the true proportions of the relative powers of the different bars, we find, by comparing columns XI. and XII., that the power of each of the six-inch bars (column XII.) was much greater than the proportion simply due to its mass (column XI.), as compared with the energy of the large bar of which it was the equivalent. In other words, that the small bars were in every case *stronger proportionally* than the large ones—and the more so, in progressive measure (with the exception above accounted for), as the masses increased. Thus whilst the six-inch equivalent of the twelve-inch bar was a little more than one-fourth stronger, propor-

tionally, than the bar with which it had to be compared, the six-inch equivalent of the twenty-four inch bar was above three-fourths stronger than its proportional one. And these results are seen to be most satisfactorily verified by the ratios, column IX., derived from the method of deviations.

2. Hitherto the degree of accuracy of the method of deviations, as applied universally to magnets of every degree of energy, extent of mass, or variety of length, had been but matter of inference; and the unimportance, practically, of the several sources of error induced by the *length* of the needle of the compass, which, for strict accuracy of comparison by direct experiment should be indefinitely short, was matter of presumption. It was, therefore, important to ascertain by actual experiment, whether the proportion of error induced by the *varying directions* of the forces of the magnets under trial with regard to the poles of the needle of the compass employed, together with the error for which the equation already determined provides,—might be such as to destroy the satisfactoriness of this method of determining the powers of magnets.

This last set of experiments, however, affords a satisfactory verification of the practical utility of the method of deviations, as applied *generally* to the determination of the relative directive powers of bar magnets. The practical measure of accuracy may be sufficiently inferred from the analogy of the ratio in column IX., determined by the method of deviations, with that of column XIII., derived from the method of torsion. In no case do the discrepancies amount to a twenty-fifth part of the whole power, though in these discrepancies are involved every other source of error in the use of the instruments employed, comprising errors of adjustment and observation, etc.

But a still more satisfactory verification is obtained by comparing the powers of the different magnets employed, as derived from the two methods of deviation and torsion, when reduced to a common standard. For this reduction, I shall take the mean of the powers as given by the six-inch equivalent bars (the last four experiments in the series), viz. 412 tangent, corresponding with 12·05 torsion, and make these amounts, in their respective class, the unit. Applying now the formula given in case II., we find that the cubes of the lengths, column I., multiplied into the tangents of deviations, column VI., afford, as the result of the method of deviations, the following series,—the mean power of four of the equivalent six-inch bars, or tangent 412, being called 1,—

6 Inch. Col. viii.	12 Inch. No. 5.	15 Inch. No. 4.	24 Inch. No. 3.	24 Inch No. 2.	36 Inch. No. 1.
1	4·9	14·7	24·7	38·1	71·3

By the method of torsion, reduced in a similar manner (the mean torsion of the equivalent six-inch bars, column xii., or 12·05 being called 1) this series is obtained,—

1	5·0	14·7	26·8	39·5	73·0

The series, by deviations, however, is unequated. If, therefore, we apply the equation due to the mean tangent = 12, we have 412—12=400, which being employed instead of 412, affords the following series of still greater correspondence with that given by the method of torsion; viz.—

1	5·1	15·2	25·4	39·2	73·0

This close and satisfactory analogy betwixt the ratios of powers, reduced to a common standard, as determined by the two methods of deviation and torsion—not only proves the sufficient accuracy of the former method, for most practical purposes, when applied generally; but this analogy verifies the formula, because of its employment in the reduction of the experiments, by the method of deviations, from which the comparison is derived.

Whilst thus we have so amply verified the practical utility and accuracy of the method of deviations for the determination of the powers of bar magnets generally,—we may take occasion, by the way, of noticing one peculiar advantage of this method above that of torsion. The method of torsion, it is observable, gives, of itself, no absolute value, nor a value whereby the results of one instrument can be compared with those of another; but the method of deviations, affords results indicative of the actual powers of magnets, by reason of its being capable of adjustment to a scale of universal applicability and comparison.

In order to this, it is only necessary to fix upon some particular length of bar and some particular distance from the compass, and then the tangent of deviation, in all places where the dip of the needle is similar, will afford a real standard of comparison, and the particular tangent decided on, an unit of the scale. In the general comparison thus yielded, the dip of the needle, by which the quantity of deviation is necessarily modified, being taken into consideration, and, if rigid precision were required, the intensity of terrestrial magnetism, the comparison would serve for all parts of the world.

The practical applicability of the method of deviations for the determination of the relative powers of straight-bar magnets, being thus satisfactorily established,—we now proceed, in the confident use of this method, to the subject proposed for investigation at the head of this chapter.

For the purpose of pursuing the contemplated inquiries on a good scale, I procured from Messrs. Stubs, a quantity of cast-steel bars, made from the same ingot, of an inch in breadth and three-sixteenths of an inch in thickness, extending to the total length of thirty-six feet. They were constructed into bars of twelve and eighteen inches each,—eighteen of the former and twelve of the latter length. The weight of each set was the same, viz. 11·31 lbs. They were all ordered to be as hard as files; some few, however, were found not to be perfectly hard, though sufficiently so for the complete satisfactoriness of the proposed experiments.

They were magnetized by various processes and with different powerful compound magnets, by the way of experiment; and, ultimately, because in this case found to be the most convenient and effective method, with two fasciculæ of busk-plate magnets, placed upright and nearly together in the middle of each bar, and then drawn asunder and slipped off sideways at the two extremities at the same time, preserving throughout an upright position.

This operation was twice performed on both sides of every bar, separately.

To render the series of experiments more complete and generally useful, the powers of these bars were tried first separately, then in pairs, end to end, or in double lengths: all the twelve-inch bars were also tried in treble lengths, and each set of bars variously combined both with these of its own set and intermingled with those of the other. The object in this latter case was to determine whether the ultimate power of large combinations would be the same when bars of different lengths were united, as when all the set combined were similar,—as such an union of different lengths would be very desirable, in order that any large mass so combined might have more firmness, and be easier bound together.

The various forms of combination are represented in plate IV.

The following results, as to the powers exhibited by the various combinations, were experimentally obtained. The several bars, it may be proper to state, were invariably remagnetized whenever they had been exposed to a greater deteriorating influence than that to which they were about to be subjected in any new arrangement; and, also, that the powers of the several bars and their various combinations were always determined by the measure of their deviations at the distance of *twice* the length of the mass or masses, under trial, from the centre of the compass. Thus the twelve-inch bars were tried, separately, at the distance of two feet from the compass; the eighteen-inch bars at three feet distance; two twelve-inch bars in one length at four feet distance; two eighteen-inch bars at six feet, etc.

1. The deviating powers of the twelve-inch bars separately, [see Plate IV., No. 1.] varied from 17° 55′ to 21° 0′; the mean power being 19° 17′, equal to tangent 350. Length of each bar, one foot.

2. A pile of ten twelve-inch bars, [No. 2] gave a power of 48° 50′=tangent 1144. Total length of steel bars combined, ten feet.—The powers in progressive combination were as follow:—1 bar=19° 5′; 2=27° 20′; 4=39° 20′; 6=46° 20′; 8=48° 30′; 10=48° 50′!—In another series in which eight of the *best* bars were selected by testing, the powers in combination were:—1=19° 5′; 2=30° 20′; 4=41° 0′; 6=47° 40′; 8=51° 34′. In another series, eight of the weakest bars being selected by testing, the

powers were:—1=20° 10′; 2=27° 37′; 4=33° 50′; 6=37° 30′; 8=41° 0′.

3. The deviating power of two bars of twelve inches each, in a line, [No. 3], being the mean of nine pairs of bars so combined, was 5° 37′=tangent 98. Length of bars combined, two feet.

4. Four twelve-inch bars (two in length and two in breadth, No. 4) gave a power of 10° 45′=tangent 190; but the same bars when tried with the two rows separated about two inches and kept in parallelism, the two bars of each row being in contact, had a power of 11° 28′=tangent 203. But the average power of six sets of these bars, so arranged with the two rows separated, was less than the above, being 10° 52′. Length of bars combined, four feet.

5. Eight twelve-inch bars, comprising two in length, two in breadth, and two in thickness, produced a mean deviation, when in contact as No. 5, of 17° 9′=tangent 309; but when these bars were presented to the compass, previously, with each of the four rows a little separated, their mean action on the compass was a deviation of 19° 59′=tangent 364.

6. The mean power of three twelve-inch bars in contact in one line [No. 6] was 2° 25′=tangent 42. When the continuity of the line of magnets was broken by slipping the middle bar out sideways, about an inch, keeping each of the

bars at the same distance from the compass as before, the power fell 0° 16′, on an average of four sets of bars; that is, the mean power of the three bars fell to 2° 9′=tangent 38. But when the series was reunited, the original powers were again restored, except in experiments where the series of three bars had been magnetized together, as one bar, when, in that case, the quantity recovered was, on a mean, 0° 8′. Length combined, three feet.

7. Six twelve-inch bars (three in length and two in breadth, all touching) gave a mean deviation of 4° 21′=tangent 76. Length combined, six feet.

8. Twelve twelve-inch bars (two tiers combined as No. 7), gave a power, in contact, of 7° 50′=tangent 138. Length of bars combined, twelve feet.

9. Eighteen twelve-inch bars, in two tiers in contact (comprising three in length, three in breadth, and two in thickness), produced a deviation of 11° 20′=tangent 200. Length combined, eighteen feet.

10. The mean power of the twelve eighteen-inch bars, separately [No. 10] was 8° 32′= tangent 150. Length of each bar, eighteen inches.

11. The total effect of the whole twelve bars of eighteen inches in length, in one pile, in

contact (as No. 11), was a deviation of 42° 0′= tangent 900. Length of the bars eighteen feet. The powers of this set, in progressive combination in the pile, were as follow:—1 bar=9° 0′; 2=15° 0′; 4=23° 30′; 6=30° 6′; 8=34° 50′; 10=38° 54′; 12=42° 0′.

12. The mean power of two eighteen-inch bars in contact, lengthways, was 2° 26′=tangent 42·5. Length combined, three feet.

13. Four bars of eighteen inches (a double row of two each) gave a mean power of 4° 40′= tangent 82. Length combined, six feet.

14. Eight bars of eighteen inches, or two tiers of No. 13, gave a mean deviation of 7° 57′= tangent 140. But the same tried previously, with all the four rows separated about an inch from each other, gave a power of 8° 25′=tangent 148. Length combined, twelve feet.

15. Twelve eighteen-inch bars (two tiers, in contact), comprising two in length, three in breadth, and two in thickness, had a power of 11° 8′=tangent 197. Length combined, eighteen feet.

16. A tier of nine bars of twelve inches, (three in length and three in breadth) with a tier upon it of six bars of eighteen inches (two in length and three in breadth) produced a deviation of 11° 8′=tangent 197. Length of bars combined, eighteen feet.

17. A three-tier magnet, with three bars in breadth, comprising nine bars of twelve inches, and twelve of eighteen, gave a deviating power of 15° 22′=tangent 275. Length of bars combined, twenty-seven feet.

18. A four-tier magnet, three bars in breadth, comprising eighteen magnets of twelve inches, and twelve of eighteen inches, placed on each other in alternate series like that of masonry, produced a deviation of 18° 42′=tangent 338. Total length of the bars combined, thirty-six feet; and total weight, 22·6 lbs.

19. The four-tier magnet [No. 18] being arranged in steps, as represented in the figure, each step being an inch, gave a deviation of 18° 22′=tangent 332, when the distance from the compass (six feet) was measured from the extremity of the nearest tier; and 19° 46′=tangent 359, when the mean position of the poles of the four tiers was taken for the measurement of the distance. The steps being reduced to a quarter of an inch each, the deviations, at the two distances taken as above, were 18° 20′ and 18° 40′. Length of bars combined, thirty-six feet.

20. The same thirty bars arranged in six tiers, two bars in breadth, all touching, gave a power of 17° 48′=tangent 321; and when afterwards opened into four separate rows an inch apart, three tiers in each row, the power increased

to 18° 48′=tangent 340. Length combined, thirty-six feet.

These various effects of contraction on the ultimate magnetic energy of the masses united, are now available for being applied to the inquiries proposed for consideration in this chapter.

I. *As to the Proportional Powers of Magnets of different lengths, but in all other respects, both as to dimensions in breadth and thickness, and in quality and hardness of steel, the same.*

Coulomb, in investigating this question with reference to magnets cut from the same wire or rod, came to the conclusion that the powers of such magnets are proportional, or very nearly proportional, to their lengths. The foregoing experiments enable us to investigate, very accurately, not indeed this precise case, but the analogous one of the relative powers of *combinations* of magnets of the same size and quality in different measures of length.

Let us, for example, compare the power of two twelve-inch bars of steel in a line, with that of one such bar. The data, for the comparison, are afforded us in Nos. 3 and 1,—constituting the mean results of several experiments with eighteen bars of the same kind. The respective powers, as shewn by the formula in case II., are here in this proportion ;—as $1^3 \times$ tangent $350 = 350 : 2^3 \times$ tangent $98 = 784$; or, as 1:2·24. But the lengths of the two bars are in the exact ratio of 1:2.

If we compare again No. 6, comprising three bars amounting to three feet in length, with No. 1, of one foot,—we have the proportional powers of $1^3 \cdot 350 : 3^3 \cdot 42 = 350 : 1134$, or 1 to 3·24. But the lengths and masses are in the proportion only of 1 to 3.

We may also compare the power of a length of two eighteen-inch bars [No. 12] with that of one such bar [No. 10]. Here the proportions are,—$1^3 \cdot 150 : 2^3 \cdot \overline{42{\cdot}5} = 150 : 340$, or 1:2·27.

To verify the result thus indicated in each of these experiments, viz.—that in a single series of magnetic bars, connected lengthways, of the description here employed, two or three bars so combined, are *stronger* than a single bar, proportionally to their lengths,—I made another special experiment, with a selection from the best of the series of twelve-inch bars. I took four of these bars, and having magnetised them fully with the bundles of busk-plate magnets, I ascertained their directive powers :—1st, singly, at two feet; 2dly, two in a line, touching, at four feet; and 3dly, three in a line at six feet from the compass. Their mean powers at these several distances were 20° 45′, 5° 55′, and 2° 41′,—

the tangents of the deviations being 379, 104, and 47. Hence their relative directive powers give the ratio of $1^3 \cdot 379$, $2^3 \cdot 104$, and $3^3 \cdot 47$; or reduced as above, of 1, 2·2, 3·345,—their real proportions, as to length and mass, being 1, 2, and 3.

This result, however, which at first sight might seem extraordinary, becomes quite intelligible when connected with another set of experiments with the same bars, made at the same time. Whilst the two series of two and three bars were respectively in their places on the "trial-board," the contact of the bars was broken by slipping the middle one out sideways, in the latter case, and the second bar, in the other case, to the distance of an inch from each other, but so that the actual distance of each bar from the compass was the same as before. Immediately, as in the former experiments (see experiment No. 6) the quantity of deviation fell to 5° 33′, with the two bars, and to 2° 32′, with the three bars; so that the series of tangents, under this arrangement, became 379, 97, 44. But here we have the entire action of the separated bars, which, apparently, ought to correspond with their united individual powers, and so constitute the exact series of 1, 2, 3. The series reduced as before, is found to be but slightly different, viz., 1, 2·05, 3·13.

The discrepancy here, if it had not been accordant with that observed in other experiments, might have been ascribed to error of observation in the deviations. But analogy suggests that the series *should* be in excess. For as the junction of the bars obviously increased, by their inductive powers, the total energy of the mass when thus favourably united—the induction, *without* contact, which must take place betwixt bars separated only by so small a distance as an inch, might reasonably be expected to produce some degree of influence.

II. *As to the Proportional Powers of Magnets combined as in the figures* (plate IV.), *compared with those in a single pile, or fasciculus.*

The results of combination, when the twelve and eighteen-inch magnets were formed progressively into separate piles [Nos. 2 and 11], enable us to form this comparison very satisfactorily.

Let us take, for instance, the case of the series of *eight* bars, arranged as No. 5 (two in length, two in breadth, and two in thickness), and we find a deviating power of 17° 9′=tangent 309. Now eight of these bars combined as No. 2, gave a power of 48° 30′=tangent 1130. The relation of these powers are $1^3 \cdot 1130 : 2^3 \cdot 309 = 1$ to 2·2; that is, the directive power of these eight magnets, when combined in the form of No. 5, is more than double that of the same series when combined in a single fasciculus. And comparing again the form No. 5, with the power of a select series of the best of the eight bars in a pile, yielding a directive power of 51° 34′=tangent 1260, we have still the preponderance in favour of the more extended combination, No. 5, in the ratio of 1·96 to 1.

Compare we again the powers of eight bars of eighteen inches when combined in the form No. 14, comprising double bars in length, breadth, and thickness, with the same bars piled up, as No. 11, in one fasciculus. The deviation produced by the longer combination, each bar touching, was 7° 57′=tangent 140, and that by the simple pile was 34° 50′=696. The relation of these powers, reduced by the formula, is found to be as 1·61 to 1.

The explanation of this fact is, on considerations suggested in the early part of this work, very intelligible. In the pile, the magnetic energy is in a more concentrated condition than in the more extended combination; hence the deterioration is much greater in the pile than in the other form.

The sum of the powers of the eight bars tried separately, as appears from the original notes of the experiments, was 1176 tangent. Hence the difference betwixt this amount and the tangent of deviation of the eight bars when in a pile, that is 1176—696=480, represents the quantity of deterioration produced by this form of combination; whilst the difference, in the other case, of 1176 and 140×2^3 or 1120=56, shews the small comparative loss suffered by the combination in the more extended form.

III. *As to the relation of the Powers of Bars of twelve and of those of eighteen inches when combined so as to constitute masses of the same form, dimensions, and weight.*

The object of this inquiry was to determine whether, in large magnetic combinations, the resulting energy of masses of given dimensions would be the same, or nearly the same, whether the longer or shorter bars of the same kind were employed.

A reference, simply, to the plate, No. IV. or to the foregoing description of the effects of each combination, will answer, sufficiently for our purpose, the inquiry before us. Thus No. 7, composed of six bars of twelve inches, and No. 13 of four bars of eighteen inches, comprise the same dimensions and masses; and their relative powers, tried at the same distance from the compass, were 4° 21′ and 4° 40′. Again, No. 8, consisting of twelve bars of twelve inches, agrees in mass and dimensions with No. 14, consisting of eight bars of eighteen inches, and their relative powers were 7° 50′ and 7° 57′. Nos. 9 and 15, likewise correspond in mass and dimensions; and their respective powers were 11° 20′ and 11° 8′. Compared by their tangents, the series of twelve-inch bars in the order above registered, gave the powers of 76, 138, 200; and the equivalent series of eighteen-inch bars, of 82, 140, 197. The greatest difference in any two corresponding masses here amounts only to 7·3 per cent. of the total power—a difference by no means exceeding the unavoidable varieties in the powers of such magnets, however carefully constructed.

IV. *As to the Relative Powers of combinations of twelve or eighteen inch Bars, each kind by itself, and those of equal masses and dimensions composed of the two kinds, intermixed.*

This inquiry was designed to determine whether magnetic bars of *dissimilar lengths* (but alike in their other dimensions and qualities) might not be combined together for the formation of magnets of great masses, with equal advantage as the combinations made out of bars of the same length. For if such an arrangement of alternating points of junction, and of alternating series of magnets of different lengths, should yield as much power as like masses composed entirely of one kind, with their points of junction all corresponding,—then would there be afforded a great convenience in arrangement, with the means for yielding solidity, when very large masses should be united as one magnet.

The cases numbered 9, 15 and 16 constitute equal masses adapted for this comparison. And here it will be perceived, that whilst eighteen bars of twelve inches gave a power of 11° 20′, and twelve bars of eighteen inches a power of 11° 8′, a tier of each kind, or nine bars of twelve inches with six bars of eighteen inches, gave a power also of 11° 8′. Hence it would appear, that bars of like description, of dissimilar lengths, may be combined together without being productive of any perceptible disadvantage to the resulting power of the mass.

V. *As to the Relative Powers of various combinations of Bars of the same description (except as to the length of the integrant bars) in* PROPORTIONAL *masses.*

Here the object of inquiry was—whether various series of magnetic bars, arranged in masses *proportional* in all their dimensions, would yield proportional powers; that is, whether the series of bars corresponding with the numbers 1^3, 2^3, 3^3, etc. (arranged according to figures No. 1, No. 5, No. 17) would afford powers corresponding with the series 1, 8, 27, etc., or, if not, in what other ratio?

The result obtained in case III. of this chapter, naturally led to the conclusion, that the powers of the larger combinations would be *below* their due proportions; but as this present inquiry related to proportional masses in *combined* magnets (a condition which is advantageous to the general result), and the other in *single* or solid masses—the investigation became necessary.

Comparing now the series of Nos. 1, 5, and 17, we have the powers, 19° 17′, 17° 9′, 15° 22′,—shewing a progressive decrease in the proportional energy. The progress of deterioration constitutes this series,—1^3·350, 2^3·309, 3^3·275= 1, 7·06, 21·2, instead of 1, 8, 27, the exact proportional power.

Comparing again the set No. 14, consisting of eight bars of eighteen inches, with the power of the single bar, No. 10, we obtain this proportional ratio,—$1^3 \times$ tangent 150 (single bar), and $2^3 \times$ tangent 140 (eight bars); or reduced as above, 1, 7·47.

Looking back for comparison to case III., however, we find the measure of deterioration below the power due to the mass, much less considerable in magnets formed by combinations of smaller pieces, than in the instance of proportional solid bars. Selecting out of the Table of experimental results, under case III., the powers of the two analogous cases of bars of twelve and twenty-four inches, we obtain by calculation the ratio 1:5·4, instead of 1:7·06, and 1:7·47, as above,—which shews that the advantage, in large masses, is in favour of magnets formed out of comparatively small bars. The case of the thirty-six-inch bar is omitted, because it was much too thin for a due comparison.

VI. *As to the extent to which small Magnets, made quite hard, may be advantageously combined, with a view to the formation of larger artificial Magnets than have yet been constructed.*

The largest combination of bars, employed in these experiments, is that figured in No. 18, which had a power, in comparison with that of a twelve inch integrant bar, as tangent 338×3^3: 350×1^3, or as 26:1; but the real proportion of the two masses was as 36:1. Still, however, the measure of deterioration was by no means so considerable as to prevent the effective combination of vastly larger masses.

Taking the experiments already made on combinations in proportional masses, however, we can obtain, by inference, a very reasonable anticipation of the effects of larger combinations. This is accomplished in the simplest manner, by throwing the cases of proportional masses, Nos. 1, 5, and 17 into a geometric curve in a diagram. Proximately, the curve yielded by the powers, 1, 7·06, 21·2, for the respective masses 1, 8, 27, combined proportionally, if prolonged to the next proportional magnitude of 4^3, or 64, would give a directive power, apparently, of about thirty-nine times that of a single bar.

Hence whilst we perceive that the deterioration of power is such as to discourage the idea of constructing permanent artificial magnets, of *limited lengths*, indefinitely large; yet such is the nature of the curve yielded by the powers of a succession of proportional magnets, that, if the proportions of the original bar be continually maintained, and the length, consequently, duly increased, there would be no limit to the extent of power obtained. Moreover, it is obvious, from the data here afforded, that magnets of very great bulk and of immense powers, may be constructed of cast-steel bars hardened to the utmost, on this principle of combination; and that if the combination were made to assume the horse-shoe form, which is favourable to the construction of magnets of inferior hardness,—a degree of magnetic energy might easily be obtained, incomparably surpassing anything yet accomplished.

The plan of combination, indeed, as is well known, was long ago put into practice by Dr. Gowin Knight, in the construction of a magnet, now in possession of the Royal Society, of extraordinary size and mass.

According to the description given of this instrument by Dr. Fothergill, executor to Dr. Knight, in the Philosophical Transactions, vol. LXVI., p. 591, for the year 1776,—it consisted *originally* of two parts, each comprising "two hundred and forty bars disposed in four lengths, every length containing sixty bars, placed in six courses or layers, in contact with one another; and ten in each course placed side by side, in contact also."*

But one of these "Magazines" of the magnetical machine was destroyed or greatly injured by a fire in the house where it was deposited; but replaced, on the same principle of construction, by Dr. Fothergill.

The whole apparatus is now enclosed in a strong box, measuring forty-two inches by eighteen and seventeen. The magnets present two poles about six inches out of, and beyond, one end of the box, so that the length of the instrument from the extremity of the concealed end to the extremity of the exposed poles, appears to be about forty-six inches.

The ends of the projecting poles measure twelve inches by three, each, and are nine inches apart.

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* My reference to this paper was taken from the Abridgment of the Philosophical Transactions by Dr. Hutton, etc. Vol. XIV., p. 117.

Dr. Faraday, in the Philosophical Transactions, for 1832, p. 135, has given a short description of the instrument, stating, "that it is composed of about four hundred and fifty bar magnets, each fifteen inches long, one inch wide, and half an inch thick." And, as to its sustaining power, it is added, that "when a soft iron cylinder, three quarters of an inch in diameter and twelve inches long, was put across from one pole to the other, it required a force of nearly 100 pounds to break the contact." What the sustaining power, however, is, by its proper conductor, is not mentioned.

So far as the instrument is visible beyond the box, I have inspected it, but could not get access, at the time, to the interior. Compared with the great mass of magnetic bars employed in its construction, however, the power was, obviously, extremely feeble,—though, doubtless, very much stronger originally. Comprising, as originally described, a weight of about 1000 lbs. of steel; or, by estimation on the data given by Dr. Faraday, betwixt 1200 and 1300 lbs. weight,—it ought to carry, if properly constructed, the weight of more than a ton.

But a curious circumstance in the construction of the instrument is mentioned by Dr. Fothergill, which, if actually still existing, must conduce greatly to the injury of the power of the machine.

Dr. Fothergill states, "that it was found difficult, after the final hardening of these bars, to preserve among them a perfect equality of size; therefore the contact of the sides was perfected by thin iron plates, slipped in between the braces and the junction of the ends of the bars."

Now this interposition of iron, or even overlaying of iron plates, must have been most injurious to the energy of the magnets—as each portion of iron, applied to any part except the neutral and transverse axis, would become magnetic in the converse direction to that of the instrument, and so neutralize a portion of the original magnetism! The only other exception to such an injurious effect would be if the iron were applied after the manner of an armature: but the description given by Dr. Fothergill of the interposed iron plates shews clearly that they were not disposed of in this way. Whether these iron plates yet remain, however, I had not the opportunity of determining.

GENERAL RESULTS.

The various points investigated in this chapter have been carried so far towards the conclusions here contemplated, that little more than a propositional summary of the several results will now be necessary.

1. That for the determination of the directive powers of straight-bars magnets of the same length, the methods of *Deviation* and *Torsion*, give, to a degree of correspondence sufficiently close for practical purposes generally, the same results.

When the angles of deviation are but small—say under 10°,—the results by the two methods are so nearly correspondent, as scarcely, if at all, to exceed the unavoidable errors of observation [see case I.]; whilst the method of deviations, both for the comparison of experiments by different persons, and for facility of obtaining results in practice, is incomparably the most convenient of the two methods.

When the deviations are large, as observed at two lengths distance of the magnets from the compass, the results, if great precision be requisite, must be equated by the method described in chapter III., Part I.; or else the deviations must be reduced in quantity, by being taken at a greater distance from the compass.

2. That the relation of the powers of magnets of different lengths, is exceedingly well determined by their action on the compass, at distances proportional to their lengths,—the tangents of deviation into the cubes of the length of the bars, respectively, yielding a ratio indicative of the several actual powers.

In the case of equal deviations being produced by bars of unequal lengths—the ratio of their powers will be simply as the cubes of their lengths.—See cases II. and III.

3. That hard straight-bar magnets, if combined lengthways, or in a straight line, with dissimilar poles touching, yield powers (within the limits and masses experimented on) somewhat greater, as compared with the powers of the single elementary bars, than what is due, proportionally, to their united length.

The amount of this increase of proportional energy, in the case of a single line of magnets so combined, is shewn, in different instances, in sect. I.

4. That when similar straight-bar magnets are combined in any extended form—that is in any form in which the length of the mass comprises more than the extent of a single bar—the directive power is always greater than when the same mass and series of bars are placed in a single pile.

The less concentration of the magnetic energy in the extended form, than in the single fasciculus, sufficiently explains, on principles already laid down, the reason of the greater amount of energy in that mode of combination.—See sect. II.

5. That sets of magnetic bars of different lengths—such as those of twelve and eighteen inches—when combined in their respective kinds into masses of the same form, weight, and dimensions, appear to yield similar degrees of energy.

Within the limits tried in the foregoing experiments—the differences betwixt the like combinations of the two classes of magnets, were so inconsiderable as strongly to support this proposition—the greatest difference in three cases of comparison not exceeding 7·3 per cent. of the total energy, and the average difference being trifling.

6. That sets of magnetic bars of different lengths, when combined so as to form several equal tiers in one mass—appear to yield similar ultimate powers as like combinations in form, kind, and dimensions, of magnets of one specific length only.

As far as this comparison could be carried with the quantity of bars made use of—this result, of much importance in its application to the construction of magnets of extraordinary masses, was very satisfactorily indicated.—See sect. IV.

7. That the relative powers of magnets, whether single or compound, when different in mass but proportional in all their dimensions, are not in

the ratio of their respective masses,—the larger masses being less strong, proportionally, than the smaller.

This proposition, as to *compound* proportional magnets, is determinable from the experiments described in the foregoing chapter, [sect. v.]—being decidedly proved even undercircumstances favourable to the improvement of the power, by reason of the combination of comparatively thin bars. Yet in every case of proportional combinations,—such as those of two bars in length, width, and thickness, and of three bars in each of the dimensions of the compound magnet,—the three-bar series was less strong, proportionally, than that of two bars, and the two-bar series than that of the average of the single bars of which the respective compound masses were composed.

In the case of *solid* magnets of different masses, but tolerably proportionate in their several dimensions—the result was the same, only the differences greater [see case III.]; the methods of torsion and deviation, whilst giving analogous results, shewing a considerable inferiority in proportional power (with respect to mass) in the larger bars. These comparative experiments shewed, that the powers of the equivalent bars of six inches in length, were nearly twice as great, proportionally, as those of bars of twenty-four inches and upwards.

8. That a compound bar, consisting of a series of magnets in a straight line, *loses* power, if the continuity of the series be broken; whilst a compound mass of more than one line of magnets *gains* power by the separation of the lines or tiers of magnets combined.

The first part of this proposition is shewn by the notes on experiment No. 6; and the second part by those on Nos. 4, 14, and 20.

The reason of the apparently different effects here produced by the separation of the magnets is very intelligible;—the separation of the bars in favourable continuity, as in the first case, depriving the magnet mainly, of the gain it had obtained by induction; but the separation of the parallel rows or lines of bars, where the contiguity of similar poles had an injurious tendency, was necessarily beneficial.

9. That the arranging of the several tiers of a large compound magnet in the form of steps at the extremities, does not appear to be of any *material benefit* to the directive power of the mass,—though, it probably may, to the lifting power of the projecting extremity.

The experiments given in Nos. 18 and 19, only go to the indication of the result of the first part of this proposition, where the gain appeared to be very inconsiderable.

10. That whilst magnets of large dimensions are less powerful, with respect to their masses, than small magnets to which they are exactly proportional in all their dimensions; and whilst the increase of the dimensions continually deteriorates from the quantity of energy due to the mass,—yet magnets may be combined in such *proportional dimensions*, with a constant increase of power, ad infinitum.

This proposition results from the nature of the curve derived from the projection of the powers of proportional magnets—which curve being of a hyperbolic character, must continue to separate to a greater distance from the line of abscissæ, however extensively prolonged.

A very different result takes places, as to the augmentation for practical utility, when many bars are combined in a single pile, or arranged within the same original extent as to length. In this case, as we have frequently seen in the foregoing Investigations, a maximum power, as to practical utility, is, whenever magnetic bars are so combined, soon attainable. And although, by the employment of hard steel plates, the attainment of this maximum is greatly protracted, yet in that kind of magnet, also, there is an obviously increasing tendency to render the accumulation of plates, after a certain amount, but little advantageous.

CHAPTER VIII.

OF THE MAGNETICAL POWERS, RECEPTIVE AND PERMANENT, OF *CAST IRON*, BOTH IN SEPARATE BARS OR PLATES, AND IN VARIOUS COMBINATIONS OF PLATES.

This portion of my Magnetical Investigations is here introduced, in order to place the magnetical powers of *Cast Iron*—a substance of a somewhat intermediate nature betwixt iron and steel—in a distinct position of comparison with reference to those of steel.

So long ago as the year 1832, I commenced a series of experiments on the magnetical recipient properties of *Cast Iron* of various qualities, with specimens furnished me by Edward Roscoe, Esq., of Liverpool. These, however, owing to the thickness of the masses employed (being an inch square) were not fitted for decisive results, in regard to the capabilities of cast iron for the magnetic condition. With the view, therefore, of a satisfactory determination of the comparative capacities of cast iron and steel, I recently added another class of experiments with plates of cast iron constructed of somewhat corresponding dimensions with those of the 7·5 inch steel plates chiefly used in the Investigations described in chapter IV.

As the investigation was one of considerable interest, with reference to the applicability of a material so unexpensive, for the construction of permanent magnets,—I obtained specimens of cast iron in considerable variety, and subjected each kind to the usual tests for the determination of its magnetical properties.

These specimens, with the exception of the series of " Run-steel," from Mr. Lucas's works near Sheffield, were obtained at the Bowling or at the Low-Moor Iron Works, in the parish of Bradford, under the kind assistance of the managers of the respective companies.

It may be convenient, in giving the results of this inquiry, first to describe the several kinds of cast iron employed in the experiments, and then to furnish, in consecutive tables, their respective powers.

1. The first set I have to describe, consisted of six plates of Bowling iron, cast out of grey, or No. 1, pig-iron,—usually considered of the best quality, and of a good description of that kind of metal. It is much less hard, being easily scratched with a file, melts easier, and runs more fluid, than the other kinds of pig-

iron. It has a comparatively dark-coloured, coarse-grained fracture. It is smelted from the best ores of the district, which ores are combined with a larger proportion of coke and lime, than in the manufacture of the pig-metal No. 2, or No. 3. The proportions of the materials combined in the furnace of course vary with the relative qualities of the lime-stone and of the iron-stone; but the proportions used in the Bowling Iron Works, in the manufacture of No. 1 pig-iron (taking the average of the seasons of summer and winter), may be considered to be about 7 cwt. of coke and 3 cwt. of lime-stone, to 6 or 7 cwt. of ore. Such is the effect of temperature or of humidity on the process of smelting, however, that the proportions of lime and coke employed in the production of No. 3 iron, in the summer, or in damp mild weather, will generally be adequate for the production of the highest quality, No. 1, in winter.

The six plates of No. 1, cast iron, employed in these experiments, were 7·5 inches long, 0·75 inch broad, 0·133 inch thick, and weighed, on an average, 1230 grains.

2. Six plates of white, or No. 3, pig-iron. This is a very hard description of metal, brittle, and of a whitish silvery-grey fracture. None of the plates of this set were scratched with the file. The proportions of lime and coke usually

employed at the Bowling Iron Works, in the production of this quality of metal, taking the average of summer and winter, are 7 cwt. of coke, and rather less than half the quantity of lime-stone, to 7 or 8 cwt. of iron-stone.

The difference of price in the market betwixt cast iron No. 1, and No. 3, is usually about ten shillings per ton.

The dimensions of the plates of this set were nearly the same as those of the preceding one, except as to thickness,—these plates being 0·14 inch thick, and of the average weight of 1400 grains.

3. Eight plates of metal, No. 1, from the Low-Moor Works. These were rather shorter than the others, being 7·2 inches in length, and 1188 grains, average weight. These were cast hard, from the "Blow-hole," a furnace heated by air thrown into it by an engine. The iron, it is considered, would have been stronger if it had been melted in an air furnace.

The average quantity of materials used at the Low-Moor Iron Works, for making a ton of pig iron, of the average quality and at the mean of different seasons during last year, is stated to have been 87 cwt. of coal, 25 cwt. of lime-stone, and 76 cwt. of iron-stone. Taken at an average, also, as to season and weather, about 15 cwt. more coal is required to make No. 1, than No. 3, pig iron.

4. Eight plates of "gun-metal," from the Low-Moor Iron Works.—This metal consists of a mixture of different qualities or castings of pig iron, selected of a good description of each kind; the object of the mixture being to obtain an union of toughness and strength. The proportions of this mixture vary according to the size and class of guns—lower numbers of metal being required, for producing the requisite hardness, in very heavy guns. The specimens furnished me were from metal prepared by an extra melting for guns for the navy.

These plates, like the former, were of the length of 7·2 inches; the average weight 1220 grains.

5. Six plates of Bowling iron from picked ore, constituting quality No. 1, pig iron, designed for ultimately being made into spring steel. This, could the result of the furnace be always calculated upon, should be a first-rate quality, being the most expensive in production of any iron made of Bowling ores.

The dimensions of the plates corresponded, except as to thickness, with the other sets of Bowling iron. Average weight 1117 grains.

6. Six plates of "*finery iron,*" from the Bowling Works, of the average weight of 1418 grains. —This description of metal is not used for casting, in any manufacture at Bowling; the process of

the refinery being employed simply as preparatory for the "puddling furnace," in order to the production of malleable iron.

Whilst the operation of the refinery improves the purity of the metal, it separates a considerable portion of the carbon and oxygen from the general mass of the iron, and yields a characteristic quality which renders the *puddling* process less wasteful and laborious, and more equable and certain in its results.

The metal from the refinery is extremely hard and brittle, close-grained, and almost of a silvery whiteness.

7. Nine plates of "*run-steel*," from the works of Edward Lucas, Esq., of Dronfield, near Sheffield.—These were of the ordinary dimensions, and weighed, on an average, 1500 grains. They were requested to be cast so as to give the greatest possible hardness.

This metal, in its original state of pig-iron, is obtained from the red hæmitite of Cumberland, smelted with charcoal, and so called "charcoal pig." The characteristic quality of run-steel is produced by a patent process for rendering the articles cast from it malleable. This is effected by cementation with the peroxide of iron, by which the superabundant carbon combines with the oxide and "metallizes" it, without undergoing fusion as in the puddling process. Thus treated, the metal is freed from the combination of elements conducing to the more characteristic peculiarities of cast iron, so as to approximate the purity of malleable iron; at the same time it retains so much of its original quality as to be susceptible of a considerable degree of hardness and polish. Hence it becomes available for the construction of a variety of articles, as a substitute for both malleable iron and steel.

8. Six plates of best *cast steel*, quite soft, were employed in this investigation, for comparison with the powers of cast-iron plates. These were of similar dimensions as the foregoing,—length 7·5 inches, breadth ·75 inch and thickness ·137 inch, and the average weight 1400 grains.

9. Three plates of *gun-metal*, Bowling. This iron consisted of a mixture of Nos. 1, 2, and 3 pig-iron, with about a third-part of old cannon melted down. It was only adapted for small guns. Length of the bars 7·5 inches, average weight 1213 grains.

10. Three plates of an inferior iron, belonging to the general denomination, No. 3, pig-iron, being the produce of "white rake-stone," a very inferior quality of ore, and a quality yielding so small a proportion of iron as not now to be worth smelting. The length of these plates was 7·5 inches, and the average weight 1138 grains.

The foregoing specimens of cast iron were, for the most part, taken from the pig or the refinery, and cast in what is technically called "green-sand," that is, moist sand, in contradistinction to dry sand, which, unless for special purposes, is ordinarily used for castings. The effect of the moisture in the sand, especially on thin plates, is to render the casting *very hard*, a condition which I was desirous of producing.

After being cast, the plates were ground to a smooth and even surface; and, being numbered with ink marks, were successively magnetized by the usual process, and with the most powerful pair of my magnets. Their powers, both separately and in combination, were then ascertained at two lengths distance from the compass, on the revolving ruler of the trial board, in the usual manner.

In addition to the varieties of cast iron now described, other specimens were obtained, and their magnetical qualities determined; but the particulars concerning them have not been included, because not contributing any thing satisfactory to the object of this investigation. Among these unrecorded experiments was the trial of a set of plates cast from *Lancashire charcoal pig*, kindly furnished me by Messrs. E. Lucas and Son; the magnetical powers of these however, though higher, were not very greatly different from the powers of the run-steel, No. 7. This set was in the rough, just as the plates were cast; but the magnetical powers did not appear to be materially, if at all, affected by this circumstance.

Besides the magnetical qualities exhibited by the experiments on the several specimens of *hard cast iron*, I tried the effect of reducing the hardness by the process of annealing. For this purpose the plates, sets 1 and 2, were placed in an iron box along with a quantity of iron scales from the smithy. The box was then placed in a small furnace and heated to redness, and then closed up and left to cool very slowly during many hours. The plates came out singularly soft, and those of No. 1, considerably ductile. But the magnetic energy, both in capacity, singly, as well as in combination, and also in fixidity, was found to be greatly injured —just in accordance with analogy in the case of the softening of steel.

The following series of Tables will give, at one view, the particulars, the most important to be determined, concerning the magnetical powers of these various sets of plates.

Magnetical Powers of various descriptions of Cast Iron, in Plates of 7·5 and 7·2 inches in length, and ·75 inch in breadth; weighing from 1000 to 1500 grains each.

No. of the Plates.	Magnetical Powers.		No. of the Plates.	Magnetical Powers.	
	Separately.	In Combination.		Separately.	In Combination.
I. *Cast Iron, No.* 1.			II. *Cast Iron, No.* 3.		
7·5 inch.—Weight, 1260 Grain			7·5 inch.—Weight, 1400 Grains.		
	° ′	° ′		° ′	° ′
1	13·53	13·53	1	10·0	10·0
2	13·52	18·10	2	10·15	12·30
3	13·35	20·34	3	10·0	14·20
4	13·37	22·15	4	10·15	15·40
5	13·46	24·26	5	9·50	16·35
6	13·20	25·47	6	10·23	17·44
Mean.	13·41	——	Mean.	10·7	——
III. *Cast Iron, No.* 1.			IV. *Gun Metal.*		
7·2 inch.—Weight, 1188 Grains.			7·2 inch.—Weight, 1220 Grains.		
	° ′	° ′		° ′	° ′
1	13·14	13·14	1	13·20	13·20
2	13·52	18·7	2	13·15	16·47
3	13·30	20·45	3	13·4	18·40
4	13·27	22·30	4	12·50	20·47
5	13·20	24·10	5	12·45	22·0
6	13·14	25·40	6	12·35	23·12
7	13·32	27·10	7	13·10	24·52
8	13·40	28·25	8	13·0	26·0
Mean.	13·29	——	Mean.	13·0	——

No. of Plates.	Magnetical Powers.		No. of Plates.	Magnetical Powers.	
	Separately.	In Combination.		Separately.	In Combination.
V. *Steel Iron.* Weight, 1117 Grains.			VI. *Refinery Iron.* Weight, 1418 Grains.		
	° ′	° ′		° ′	° ′
1	10·32	10·32	1	12·29	12·29
2	11·33	15·8	2	12·40	16·16
3	12·18	18·9	3	12·7	18·14
4	11·14	19·24	4	11·45	20·4
5	8·42	20·10	5	12·19	21·36
6	11·53	22·0	6	12·1	23·15
Mean.	11·2	——	Mean.	12·13	——
VII. *Lucas's Run Steel.* Weight, 1500 Grains.			VIII. *Soft Cast Steel.* Weight, 1400 Grains.		
	° ′	° ′		° ′	° ′
1	9·40	9·40	1	13·15	13·15
2	10·32	13·10	2	13·20	16·4
3	10·15	14·10	3	13·25	17·37
4	10·10	15·55	4	13·23	18·45
5	10·12	17·0	5	13·12	19·55
6	10·32	18·30	6	13·47	21.50
Mean.	10·13	——	Mean.	13·24	——
IX. *Gun Metal.* 7·5 inch. Weight, 1213 Grains.			X. *White Rake, No.* 3 *Iron.* Weight, 1138 Grains.		
	° ′	° ′		° ′	° ′
1	9·35	9·35	1	8·42	8·42
2	9·15	11·42	2	8·35	11·15
3	9·8	13·14	3	8·58	12·28
Mean.	9·19	——	Mean.	9·19	——

It may be proper to notice, in connexion with the specimens used in these experiments, that the characteristic difference betwixt the various qualities and kinds of cast iron produced in the works from whence they were supplied—is considered mainly to arise from differences in the quality of the ore, and from differences in the *proportions* of the materials used in the smelting. Thus, from the greater quantity of coke employed in the production of "No. 1, pig metal," there is supposed to result a larger proportion of carbon in combination with the metal. Hence, No. 1, pig metal, has been described as a supercarbonated crude iron; and No. 3, as a "carbo-oxygenated crude iron."

These distinctions, however, are not universally acknowledged; for some chemists consider that the characteristic differences observable in the several kinds of cast iron are rather owing to the mode of combination of the constituent elements, than in the quantity of carbon. But the result of these experiments would have led me to infer that there is a predominance of carbon in the quality No. 1, pig-iron.

Whatever be the characteristic quality of iron, ordinarily produced from any specific kind of ore, or proportion of materials; this, as we have already remarked, is subject to considerable differences, arising from other causes. Thus, besides the effects of management in the process of smelting, both the *quality* and *quantity* of the produce of the furnaces are found to be essentially influenced by the temperature and by the hygrometrical and electrical (?) state of the atmosphere—a low temperature and dry air being decidedly favourable, and warmth and dampness, or an electric condition of the air, being considered unfavourable to the manufacture of cast iron.

Reasoning on the analogies with regard to the magnetical properties of steel, compared with those of iron,—I had supposed that the magnetical qualities in cast iron should increase with the predominance of the carbon, and diminish both with the diminution of carbon or proportional predominance of oxygen :—considering that it was probably the predominance of either of these alterative elements to which, in considerable measure, the different magnetical capabilities of the metal were to be ascribed.

This idea, if not fully substantiated, is not altogether disproved by the foregoing experiments, in which, it is observable, that the quality of No. 1, pig metal, usually considered as the most highly carbonized, exhibits, among the various kinds of iron examined, the highest magnetical qualities ; whilst the refinery iron, which clearly possesses less carbon than the others, has lower magnetic qualities.

The proportional energy and fixidity of magnetism in cast iron, it will be seen, are *low* in comparison of these properties in *hard steel;* but not so if compared with plates of like magnitude of soft, or slightly tempered, steel. And it is by no means improbable, but peculiar specimens of cast iron from other ores might afford still higher capabilities for the magnetic condition.

In diagram, No. 5, the magnetical powers of the best cast iron are represented by one of the lowest curves, where they can be compared, by the eye, with the powers of both *soft* and *hard* steel plates of various denominations. The relative powers of plates of *soft* cast steel appear in the lowest curve of the whole; and those of a series of solid bars of blister steel, tempered at the ends, weighing 1580, 2630, and 5280 grains, respectively, constitute the intermediate curve betwixt hard cast-iron and soft cast-steel. The conclusions arrived at from this examination, with a more definite view of the proportional powers and magnetic capabilities of cast iron, are given in the following summary of Propositional Results.

RESULTS.

NOTWITHSTANDING the variety of specimens of *Cast Iron,* subjected to experiment for the trial of their respective magnetic properties, only a very few general results are suggested by these Investigations. The following, however, seem to be fairly borne out by the experiments.

1. That *Cast Iron* possesses considerable powers for magnetism, both in capacity and retentiveness, though greatly inferior in both qualities to those of properly hardened steel.

A very cursory inspection of the preceding tables will be sufficient to justify this general proposition.

2. That the best qualities of cast iron, distinguished by their higher value in commerce—seem to possess, unless very deficient in carbon, the highest magnetical properties.

Thus the quality No. 1, pig, which usually bears a price in the market of about 10*s.* a ton higher than that of No. 3, is seen to possess a great superiority in its magnetical qualities,—see set No. I. and No. II. So also, Low-

Moor gun metal, steel-iron, and finery iron, exhibit good magnetical qualities; whilst the commoner iron, sets II. and X., and the mixed, set IX., give lower degrees of energy.

The low energy of set IX., was probably occasioned by some accidental cause—either by the casting being less hard, or by being incorporated with a decarbonized quality of old metal.

3. That in any particular quality of cast iron, the hardness produced by the rapid cooling of the casting, is favourable to the magnetic energy.

The experiment on the annealing of sets No. I. and II. referred to at page 338, abundantly proved this reasonably anticipated result.

4. That the existence of carbon in the cast iron, appears to be beneficial to its magnetical properties, and the processes for decarbonizing, therefore, injurious.

The low powers of the "Run steel," set VII., which, in its general qualities promised to be superior, indicates, I think, that this proportion is accordant with fact. And even the case of the refined iron, set VI., the powers of which are very considerable, does not militate against this conclusion; since the refining process, whilst it improves the purity and increases the hardness of the iron, leaves it ultimately of lower magnetical capabilities than before its being thus partially decarbonized.

The experiment with iron, cast from Lancashire charcoal pig (page 337), did not fulfil the expectation formed concerning that quality. It is difficult, however, from any single set of castings, to draw general conclusions; as an accidental peculiarity in the portion of original metal selected, or in the method of casting, might have a considerable influence on the resulting character of the plates.

5. That in relation to steel, the magnetical properties of the best kinds of cast iron, are equal, if not greater than, those of *soft* cast steel [*C.* S.] in single, medium, or thick plates; and considerably superior to soft steel in large masses or in combinations of several plates.

Comparing tables I., III., and IV., with that representing the power of soft cast steel, VIII., this result is clearly established; whilst the lower curves in diagram, No. 5, exhibit the fact plainly to the eye.

6. That cast iron of the best magnetical qualities, such as No. 1, pig-metal, if cast very hard in thin bars or plates, appears to be capable, by combination, of forming as powerful magnets as, or even more powerful than, *solid massive bars* of ordinary steel if only hardened slightly at the ends, or in the manner heretofore commonly adopted in the construction of magnets in this country.

This is a result drawn from a comparison of the powers of the cast-iron plates given in the foregoing tables, especially of sets I., II., and IV., with the powers of a series of solid bars, tempered at ends, E, as shewn in page 343. A result, very nearly accordant, was derived from a like comparison of the cast-iron 7·5 inch plates, with the set of cast steel six-inch bars, E, tempered at the ends, represented in the diagram, plate II. The relative powers being reduced to a common standard in relation to the different lengths, it appeared that, in masses below 6000 grains weight, the solid *steel* bars (in the case of magnets of 7·5 inches in length) had the advantage; but the curve of the powers of cast-iron plates crossed that of solid bars, tempered E, at the weight of about 6000 grains, and beyond that weight the cast iron appeared to gain the pre-eminence.

CHAPTER IX.

ON THE MEASURE OF PERMANENCY OF THE ENERGY IN STRAIGHT-BAR MAGNETS, BOTH SINGLE AND COMPOUND, AND OF DIFFERENT DEGREES OF HARDNESS, AS SELF-SUSTAINED, OR AS INFLUENCED ONLY BY TERRESTRIAL MAGNETISM.

All artificial magnets, especially those in a highly energetic condition, are subject to deterioration of power, unless particularly protected by conductors betwixt contrary poles, or other sustaining influence.

Questions of considerable interest and importance, as concern the use and efficiency of magnetical instruments, naturally arise out of the knowledge of this tendency to deterioration. What may be the rate of deterioration in the energy of magnets, as accelerated or retarded by terrestrial magnetism? what may be the relative effects of various degrees of hardness on the retentiveness of the magnetic condition? and, whether the permanency of *combinations* of magnetic plates or bars be as great as, or greater than, that of single or *solid* bar magnets? The permanency here referred to, it should be observed, is not as to fixidity under the action of magnet upon magnet; but that of the simple sustaining power of the substance of which the magnet is composed, under the mere operation of the ordinary tendency in the magnet to return to a neutral condition, or as affected only by terrestrial magnetism.

The inquiries herein suggested, evidently belong to the results of continuous action in the influences tending to deteriorate the magnetic energy; inquiries, therefore, only to be answered satisfactorily by repeated experiments made on the same magnets, cautiously laid by, after considerable intervals of time.

For this purpose, trial of the permanency of the magnetic condition was made on a variety of plates and bars, both single and compound; the plates in some of the latter being separated throughout by discs of wood, some separated partially, and others placed together in contact. And although with the more extensive combinations the investigations were but imperfectly carried out; yet enough has, I conceive, been accomplished for shewing the relative conservative power both of the compound arrangement of magnetized plates (having reference to forms of combination suitable for the directing magnets or needles of sea-compasses) and of single bar magnets, during considerable periods of time.

Sect. I.—In the first instance, I instituted a comparison, in a series of twelve experiments, betwixt different sets of thin two-feet magnetical plates, tempered throughout, six in each set, and separated by discs of about the tenth of an inch in thickness; and four-bar magnets of two feet in length, of considerable power, two of them being tempered throughout, and two only tempered at the ends. The experiments with the series of thin plates, were made at one length distance from the compass,—those with the bars, at two lengths; but the comparison as to the proportion of loss is equally satisfactory. During the interval betwixt the two trials of their powers, the several sets of plates, or bars, were left without conductors, at a considerable distance from other magnets, and generally laid in a horizontal position, *east* and *west*, so as to derive neither support nor injury from the earth's magnetism. And each bar or set of plates, was, for the most part, first tried immediately after being magnetized, or combined in series, so as to be in its most energetic condition.

The annexed table exhibits the results of the experiments for determining the change, or subsidence, in energy of combinations of six magnetized steel plates, of two feet in length, when left, for a specific period, unprotected. The weight of each set of six plates was about 2·5 lbs.

Series of Plates.	Interval of time in days.	Power when first tried.		Power when re-examined.	
		Mean Deviation.	Tangent.	Mean Deviation.	Tangent.
		° ′		° ′	
A	3	56·15	1497	55·45	1469
B	3	55 25	1450	54·48	1418
A	4	54·40	1411	54·20	1393
A	7	54·40	1411	54·17	1391
A	11	54·18	1392	54·23	1396
B	3½	55·25	1450	54·45	1415
C	3½	54·3	1379	53·5	1331
E	3½	52·32	1305	51·17	1247
A	23	56·3	1485	55·51	1474
B	23	53·57	1374	53·9	1334
F	23	48·50	1144	48·46	1141
B	6	54·43	1413	54·25	1398
Mean	9·46		1392·6		1367·2
Average loss per cent. in 9·46 days,=1·82.					

The retentiveness of these various sets of combined plates, as compared with that of single-bar magnets of corresponding length and breadth, was tried by examining the magnetic powers, respectively, of various single bars, after certain intervals of time—commencing with the highest magnetic energy of which they were susceptible.

The experiments for determining the subsidence of energy in four separate two-feet bar magnets of considerable power, when left, for a short specified period unprotected, are herein exhibited. Each of the bars X were of the weight of about 6¼ lbs.; those marked Y were a little under 3 lbs. weight each.

Description of Bars.	Interval of time. Days.	Powers when first Magnetised.		Powers when re-examined.	
		Deviation.	Tangent.	Deviation.	Tangent.
		° ′		° ′	
X 1.	3	14·35	260	14·24	257
X 2.	3	15·7	270	14·44	263
Y 1.	3	7·41	135	7·31	132
Y 2.	3	7·45	136	7·41	135
Y 1.	10	7.41	135	7·29	131
Y 2.	10	7·45	136	7·38	134
Sum.	32		1072		1052
Mean.	5·3	Loss per cent. in 5·3 days=1·87			

As far as these experiments go, we find, that the subsidence, or loss of power, in the single-bar magnets wherein the tension (or total energy) was inferior, was even greater in 5·3 days, than that of the combination of plates, in 9·46 days—indicating a permanency, or tenacity of power, in favour, on the whole, of the compound series.

The loss of power per cent. in these experiments, during so short period, is not to be considered as by any means implying that a corresponding loss of power would take place in subsequent similar periods. For in some single experiments, made with other sets of plates, a very remarkable tenacity was observed during far longer intervals of time. The immediate loss of power here observed is comparatively great, because of the bars or plates being magnetized beyond their strength for retention; but if the first tendency to subside be somewhat aided by the juxta-position of other adverse or opposing magnetic influence, the power will at once sink to a certain extent, and then the subsequent deterioration, from mere subsidence of power, is found to be less considerable. And when that adverse magnetic influence has been considerable—such as that of a moment's contact of the extremity of a bar or series of plates with the like pole of another magnet—then the power is found in certain cases to sink even below the real strength of the magnet for retention, so as to be recovered in some measure by being laid in a favourable position, or within the influence of the converse polarity of another magnet. In one example, the fifth in the series of the first of the tables just given, an increase of the original power was indicated; but whether this arose from some such accidental influence, or from error of observation, I have no means of satisfactorily determining. But, notwithstanding the discrepancy of that particular example, I could not feel justified in excluding it from the series.

In order to shew the measure of permanency in the compound series for more considerable intervals of time, and likewise the diminishing deterioration after the first, I would next adduce an experiment with two sets of smaller plates, to which the table at page 137 refers. After the experiments specified in that table, each series of plates, twelve in number, was tied tight with twine, and laid aside, being kept carefully clear of all other magnets, as well as of each other. The powers of both series, at two lengths from the compass, previous to being put aside, with their powers on examination after intervals of one day, and of sixty-four days, were as follows:—

	Original Power.		Power after 1 Day.		Power after 64 Days.	
	Mean Deviation.	Tangent.	Deviation.	Tangent.	Deviation.	Tangent.
	° ′		° ′		° ′	
Harder Series, reduced only in the middle.	24·57	465	24·5	447	22·50	421
Softer Series, reduced throughout.	23·21	432	22·32	415	20·30	374

Now these observations indicate a loss of power in the harder, of 3·88 per cent. in the first day, and of 5·82 per cent. in the *next* sixty-four days; and a loss of 3·93 per cent. in the *softer* series, the first day, and 9·88 per cent. in the next sixty-four days. The greater degree of permanency of the harder plates is here very decidedly shewn—which, probably, would have been still more striking had a comparison been instituted with other plates in which the difference of temper was greater. The position of these bundles of plates, when laid up in the intervals of the trials of their powers, was in the line of the magnetic east and west, nearly; hence, in a condition in which terrestrial magnetism became inoperative.

Sect. II. The measure of permanency of the magnetic condition in smaller bars of various degrees of hardness, both single and compound, but chiefly single, was tried for much longer intervals of time.

In one series of experiments, plates and bars, both single and compound, of the length of 7·5 inches were employed. These consisted of a moderately hard bar of shear steel (about the temper T) of 5310 grains weight; three plates of shear steel, weighing about 650 grains each, of different degrees of hardness; and a compound bar of three plates of hard cast steel tied together, weighing nearly 2000 grains.

These five magnets (all being magnetized in the highest degree) were laid in a cabinet, sufficiently separated to guard against any sensible influence from each other, with their marked ends toward the north—or in the direction they would have assumed if suspended on a pivot as compass needles. After remaining about two months, their powers were examined; when there appeared a *very slight* subsidence (scarcely amounting to two per cent. on the whole) of the original energy, being the greatest in the heaviest bar of shear steel. The magnets being replaced in the cabinet, as before, were allowed to remain, with only one trial intermediately, for rather more than a year, when they were again placed in succession on the ruler of the *Trial-board,* and their directive powers determined. In four out of five (the other having been removed during the interval) the powers were so nearly the same as they were a twelve-month before, that the alterations did not exceed the small discrepancies which might be expected to arise from the errors of observation and of the adjustment of the apparatus: for the average deterioration did not exceed a four-hundredth part of the whole power.

A second series of experiments was coincidently proceeded with, in which six-inch plates and bars were employed. These consisted chiefly of selections, of different degrees of hardness, out of the series employed in the Investigations of chapter v., Part I.

This set of bars was treated somewhat differently from the former—three of them, after being fully magnetized, being slightly reduced by being placed near the test bar, with similar poles contiguous, at the distance of two inches above it.

The effect of this is shewn in the annexed table by the differences, in the case of the first three bars, betwixt the powers in columns III. and IV. In the case of the last three bars (one of them being compound), where the powers in column IV. are marked with an asterisk, no reduction of the maximum powers was made.

The powers of the bars, when first placed in the cabinet, October 22, 1841, are given in column IV.; their respective powers, when examined March 21, 1842, in column V.; and their powers when again tried, March 27, 1843, in column VI. The position in which the bars lay was in the direction of the magnetic meridian; the marked ends towards the north.

Mark of Bars.	Weight in Grains.	Maximum Powers.	Powers as placed in Cabinet, Oct. 22, 1841.	Powers as tried Mar. 21, 1842.	Powers as tried Mar. 27, 1843.	Loss per Cent.		
						In 5 Months.	In 17 Months.	In the intermediate 12 Months.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
		° ′	° ′	° ′	° ′			
H. ii.	1404	32·37	32·8	31·50	31·3	1·1	4·1	3·0
T. ii.	1535	28·55	27·40	27·26	27·23	0·9	1·1	0·2
E. ii.	1518	20·56	19·37	19·22	19·23	1·0	1·1	0·1
T. iii.	710	22·57	22·57*	22·25	22·25	2·4	2·4	0 0
E. iii. iv	984	21·46	21·46*	21·10	20·49	3·0	4·8	1·8
S. i.	3650	18 52	18·52*	18·45	18·29	1·1	2·4	1·3
Mean Results -			——	——	——	1·6	2·7	1·1

Comparing the tangents of the deviations given in columns IV., V., and VI.; we obtain the loss per cent. in each bar after an interval of five months, as given in column VII.; of seventeen months, as given in column VIII.; and in the interval of the intermediate twelve months as given in column IX. Three of the bars, it will be observed, suffered scarcely a sensible loss,—the mean loss being only one-tenth per cent. The greatest loss, it is remarkable, was found in the case of the hardest bar, H ii. But this seems so contrary to analogy, that a suspicion necessarily arises that it must have received some accidental deterioration whilst under trial.

Here we find the average loss, in the first five months, to be 1·6 per cent., and in the intermediate twelve months 1·1 per cent.; total 2·7 per cent. If we compare the bars which were *slightly* reduced by proximity to the test-bar, with those placed in the cabinet at their maximum energy, we find an average loss of 2·1 per cent. in the former, and of 3·2 per cent. in the latter—a result which was naturally anticipated. Were we, indeed, to omit the apparently defective experiment of bar H ii., we should have a mean deterioration in the unreduced bars of 3·2 per cent. in seventeen months, and of the reduced bars of 1·1 per cent.; and a mean deterioration of the same, in the last twelve months, of 1·0 and 0·1, respectively. It will be observed that the proportional loss of power does not, in this case, seem to be so materially in relation to the degree of hardness as might have been anticipated; and that magnets of moderate powers, of any measure of hardness, if placed properly in the magnetic meridian, and kept at a distance from all other magnetic influences, are capable of retaining their powers, with little or almost no loss, for long periods of time.

The bars employed in these latter experiments were re-magnetized to their highest capabilities immediately after their several powers, as given in column VI. of the preceding table, had been determined. Their powers having been again tried, they were placed, as before, in a horizontal position in the cabinet, with their marked ends towards the north. On the 27th of October, 1843, an interval of exactly seven months, they were again examined. No perceptible loss of power, on the average of the series, could be detected; on the contrary, some of the bars seemed to have received a slight augmentation of power by the favourable action of the earth's magnetism. The mean powers of five bars remained the same as at first. The compass, however, having in the mean time undergone repairs, and the agate in the central cap having been changed, it was impossible to determine whether or not there might be some slight alteration in the centring of the needle sufficient to effect, in a very minute degree, the indications of the instrument.

The experiments, I may here observe, relating to the property of steel for sustaining the magnetic energy, are matters of very great delicacy of management, because of the extreme susceptibility of that property under any extraneous magnetic influence. For not only may an instantaneous approach of one magnet within the sphere of influence of another magnet alter the power of the former, or of both; but even a change in the position of a highly magnetized bar from the horizontal to the vertical, may produce a very perceptible alteration in the deviating power of such bar.

RESULTS.

Though this part of my Investigations has not been carried to the extent which I could have desired, and, though the results are not in every respect accordant with presumed analogies; yet so much appears satisfactory as to justify, I think, these general conclusions:—

1. That the degree of *retentiveness* of magnets is directly as the hardness, and inversely as the energy.

Taking all the causes of deterioration into account, such as the action of terrestrial or other magnetism in unfavourable directions, this proposition will be found a general law; though under circumstances of favourable position, in regard to the direction of the earth's magnetism, the effect of hardness, on the one side, or of great energy, on the other, may not, in moderate intervals of time, be very perceptible.

The difference in retentiveness observable betwixt the softer and harder series of plates described at the conclusion of § 1, is corroborative of the proposition under consideration—the loss sustained by the *softer* series in 64 days being 9·88 per cent., and by the *harder* set only 5·82.

2. That the loss of energy by time, in unprotected magnets, whether single or compound, is much more considerable at first than subsequently.

In the case of the two compound series of smaller plates described at page 354, we find that the harder lost two-thirds as much power the first day, as it subsequently did in 64 days.

And in the case of the several six-inch bars, the effects of time on the magnetism of which are shewn in the table at page 357, nearly one-half more deterioration occurred in the first five months than in the subsequent twelve months.

3. That *combinations* of magnetized plates of tempered or hard steel, appear to be fully as favourable for the retention of the magnetic energy as single magnets of similar mass, and probably more retentive than single bars of corresponding power,—especially if the plates in combination be separated to a little distance from each other so as to attenuate the *intensity* of the energy in the compound magnet.

This result is deduced from the considerations drawn from a comparison of the tables at page 352 and page 357.

4. That in magnets of moderate powers, though fully magnetized, if kept clear of deteriorating influences and placed in the direction that would be assumed by the suspended compass needle, the power is very enduring; and but little, if at all, less so, in *soft* than in *hard* magnets.

In the first series of experiments described in sect. 2, consisting chiefly of plates adapted, as to weight, for compass needles, the loss of power when laid in the magnetic meridian was scarcely 2 per cent. in the first two months, which loss was not perceptibly increased during the subsequent period of a year.

Again, in the second series of experiments of sect. 2, the same result is partly verified. And in a subsequent experiment, not included in the tables, no loss of power could be at all discerned in a period of seven months, even after the bars had been re-magnetized to their highest capabilities; nor was any perceptible difference observed, in this case, betwixt the sustaining power of the soft and that of the hard bars.

Hardness, therefore, becomes most essentially important for resisting the effects of *unfavourable magnetic action*, whether arising from the earth's magnetism operating against that of the magnet, or from unfavourable contact with, or proximity to, any other magnet. In another respect, also, as has been repeatedly shewn, hardness is of essential moment; that is, for enabling large magnets to sustain the violence belonging to the condition of powerful combinations, or massive bars.

In the experiments with the two energetic compound bars, of different degrees of hardness, described at page 354, the harder bar exhibited an advantage over the other in its relative tenaciousness; but in this case the magnets were very powerful ones, and the position in which they were laid by (east and west), had not the advantage of terrestrial magnetism for assisting in retaining the power.

5. That when the maximum power of a magnet is slightly reduced by unfavourable

proximity to another magnet, the resulting energy is still less influenced by time.

This is a result which had been fully anticipated, and is well illustrated by the experiments exhibited in the table at page 357. For here we find (excluding the first bar in the table as an anomalous case, and apparently defective in accuracy) that whilst the unreduced bars lost, on an average, 3·2 per cent. in seventeen months, the bars that had been slightly reduced lost but 1·1 per cent. of their power; and that these reduced ones, in the last twelve months, sustained scarcely any sensible loss.

END OF PART II.

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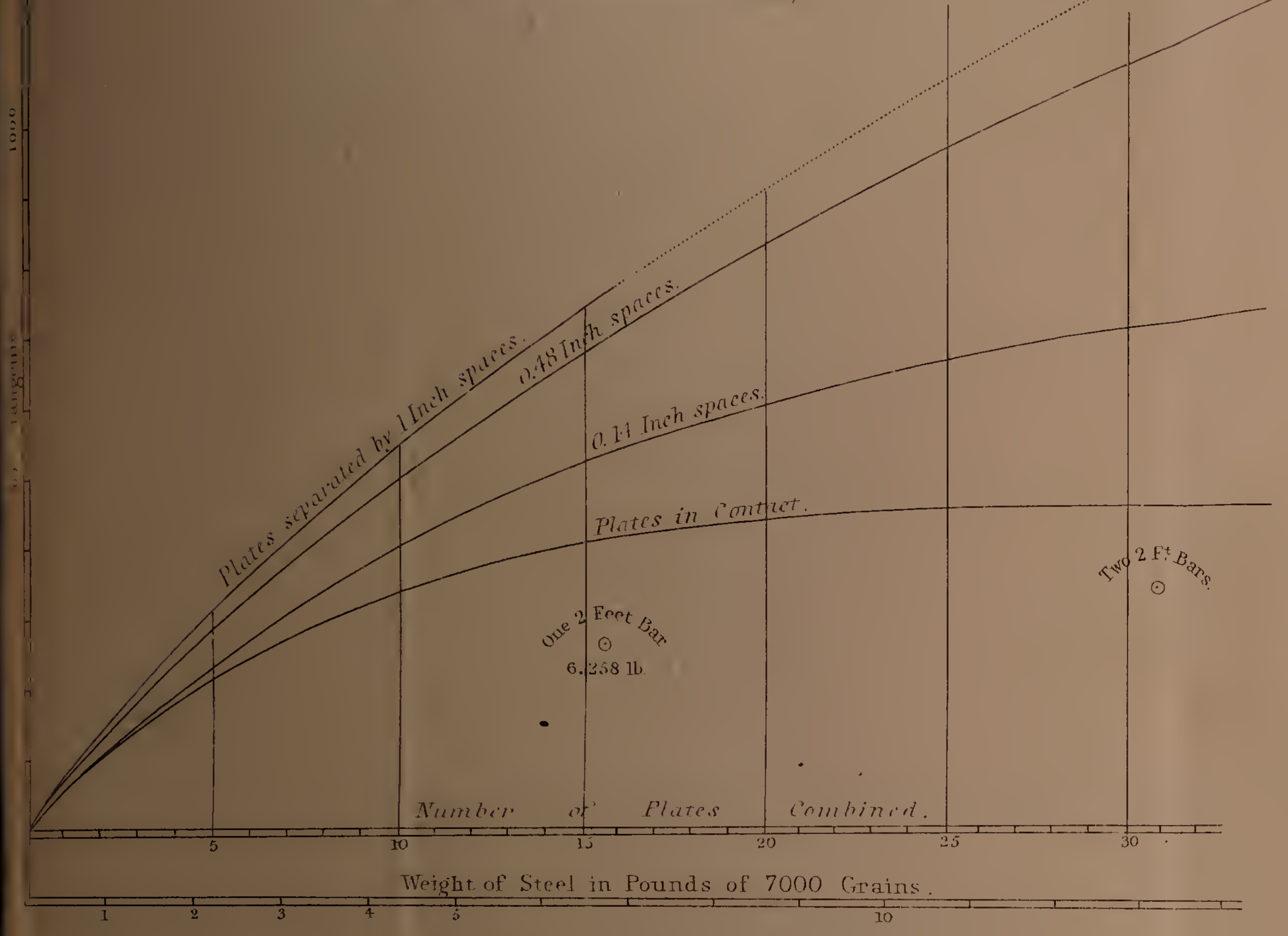
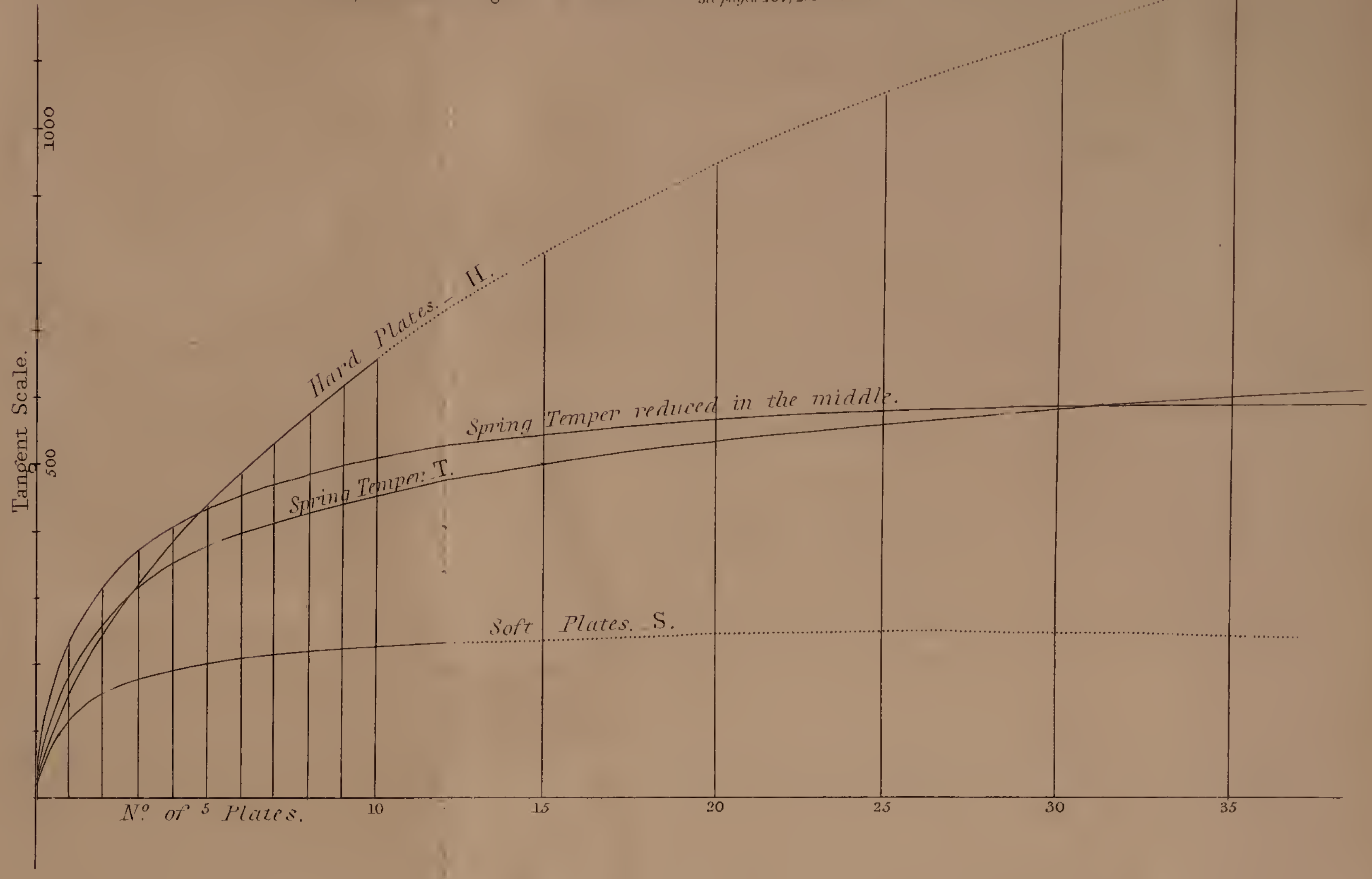
DIAGRAMS REPRESENTING MAGNETICAL POWERS.

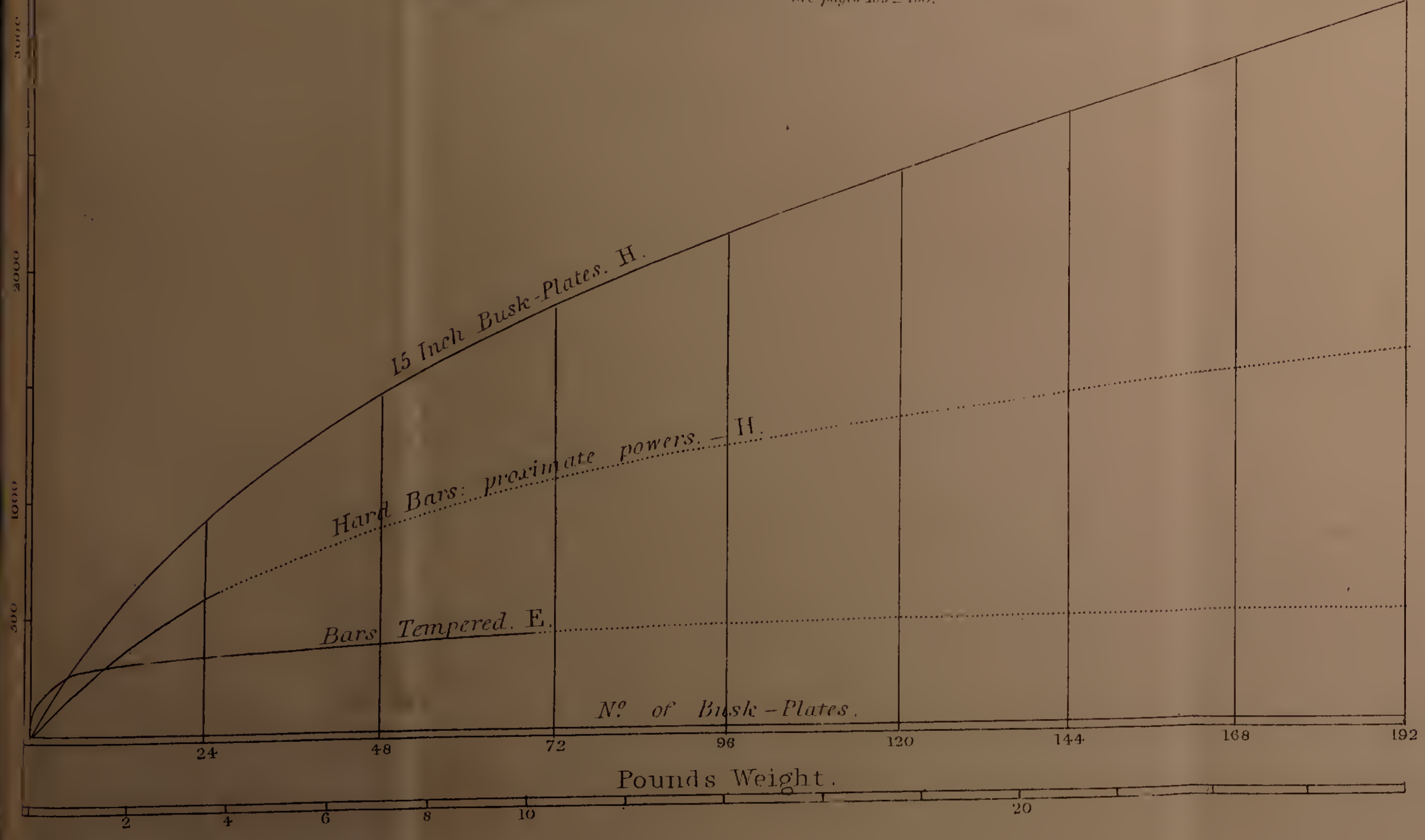
Nº 2. _Comparative Powers of Combinations of Magnetized Cast Steel Plates, Spring Temper, T, 24 Inches in length. *See Chap. II.*



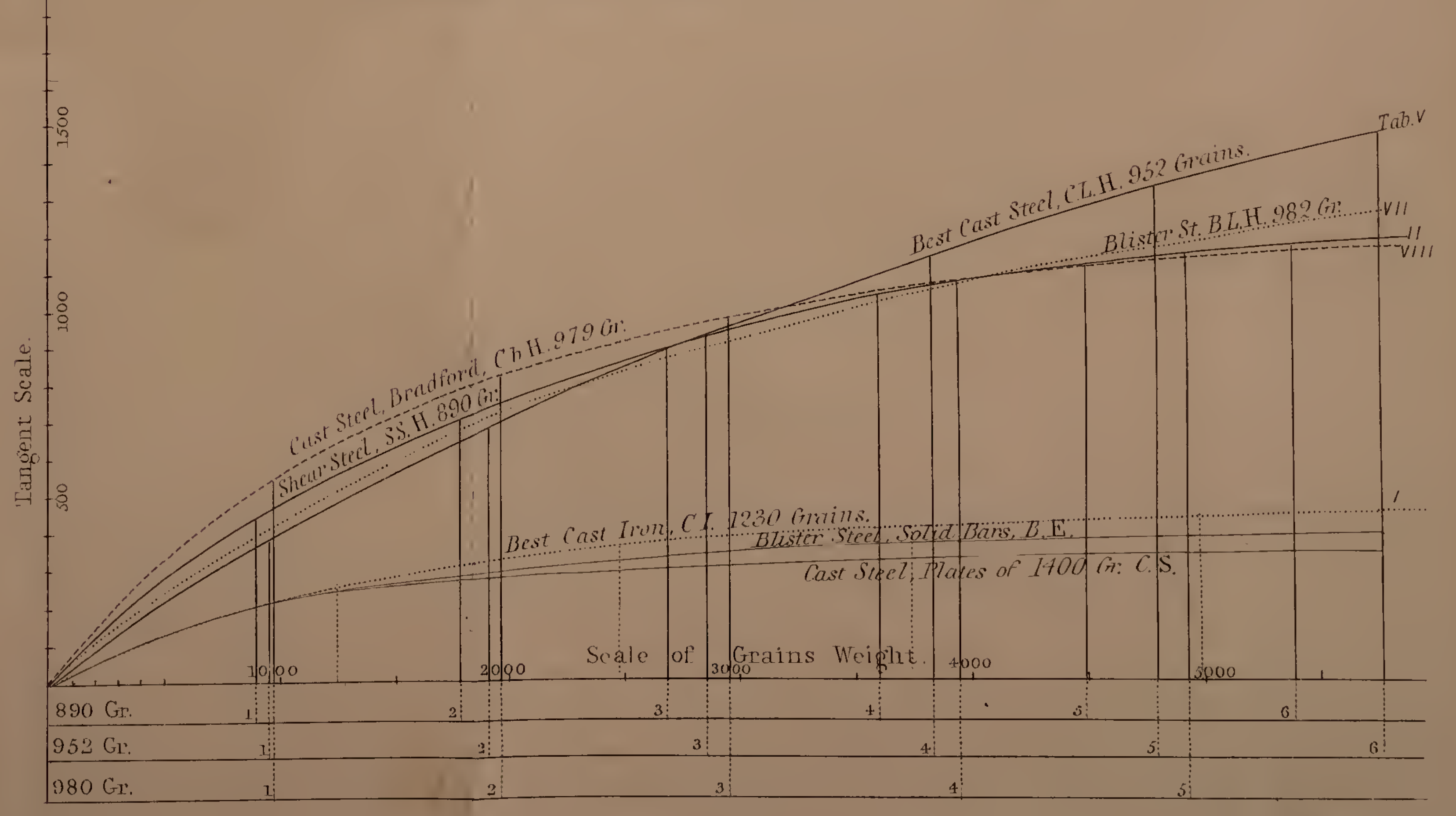
Nº 4._Powers of Cast Steel Plates, 8.7 Inches in length and 370 Grains Weight, each, of various degrees of hardness. *See pages 137, 151 & 174.*



Nº 3._Comparative Powers of Hard Cast Steel Busk-plates, and of Combinations of Solid Bars. *See pages 159 _ 165.*



Nº 5. _Comparative Powers of 7.5 Inch Steel Plates of different kinds, and of Cast Iron, in sets of 6 Plates of each kind. *See Chapˢ IV & VIII.*



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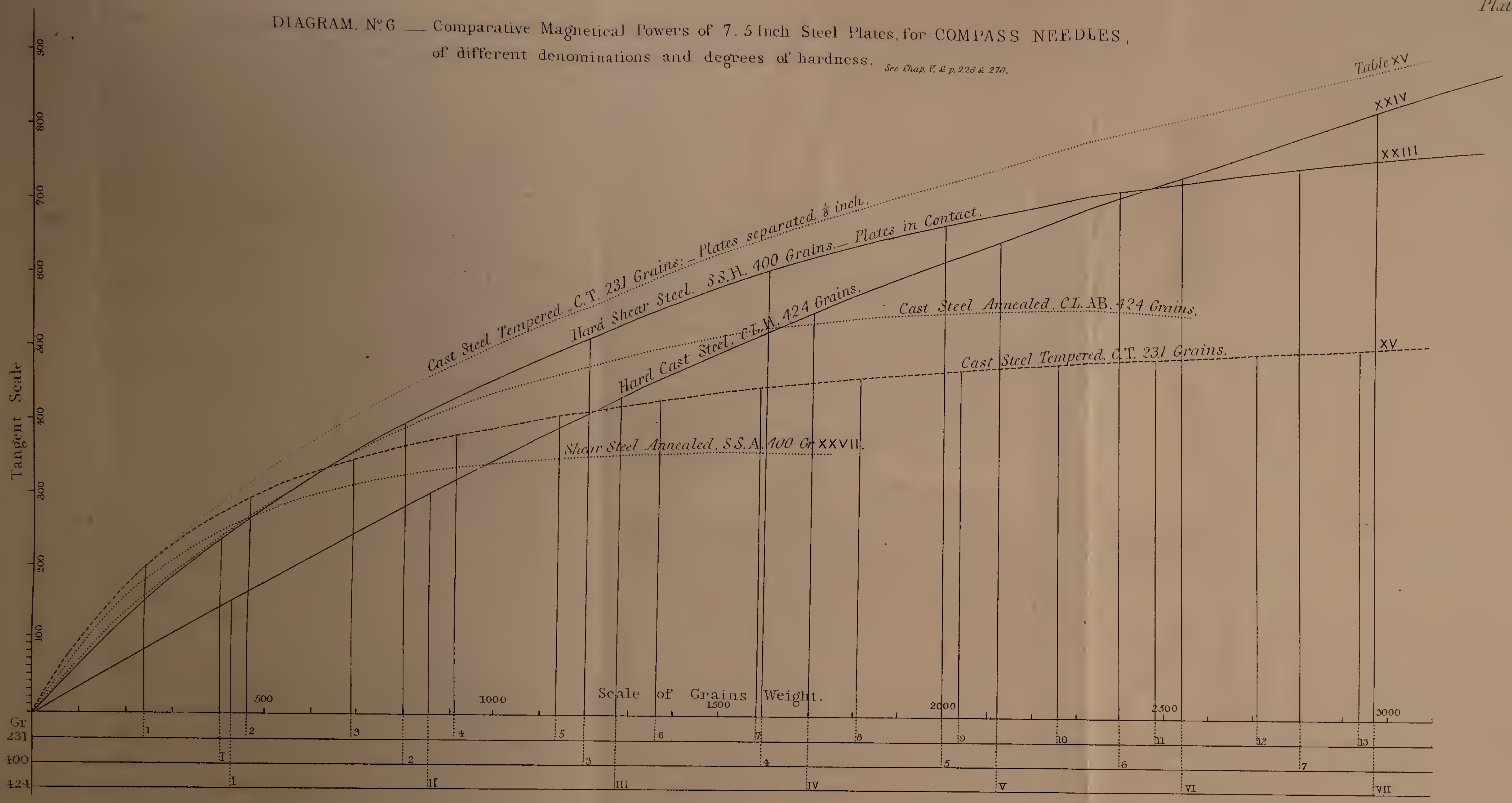
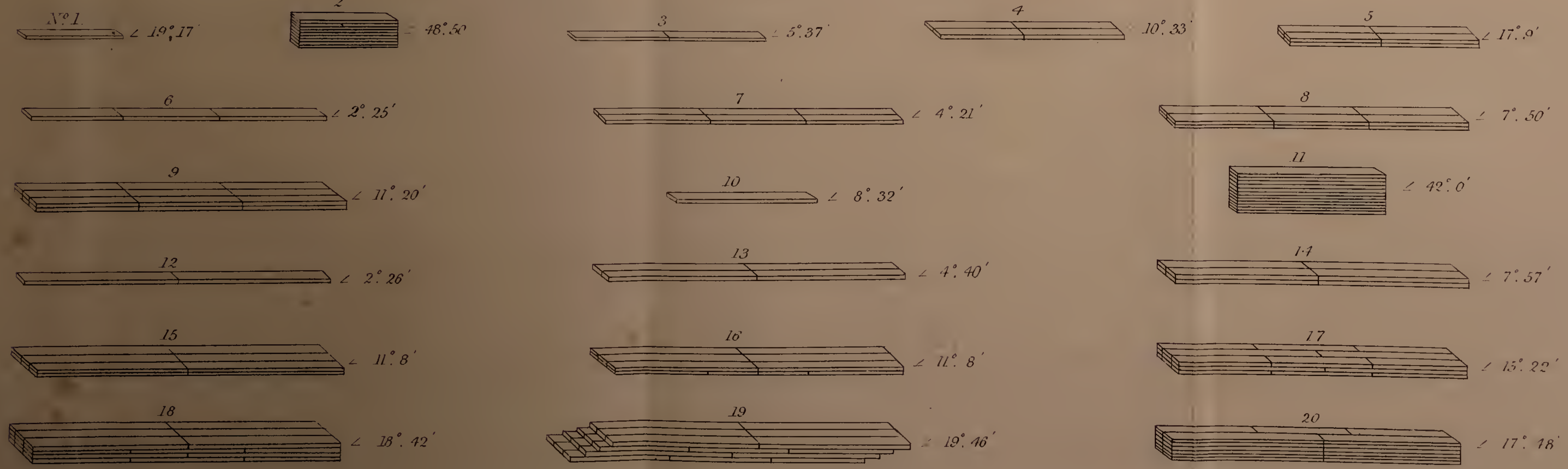


DIAGRAM. No. 6 — Comparative Magnetical Powers of 7.5 Inch Steel Plates, for COMPASS NEEDLES, of different denominations and degrees of hardness. *See Chap. V. & p. 226 & 270.*

POWERS OF MAGNETS VARIOUSLY COMBINED.

Deviations at 2 lengths of each Figure from the Compass.



H. Adlard, sc.

October 2, 1843.

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" " Porcelain & Glass	ib.
Savage's Dictionary of Printing	26
Ure's Dictionary of Arts, Manufactures, and Mines	31
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Harford's Life of Dr. Burgess	11
Jackson's Life of Wellington	13
James's Life of the Black Prince	14
" Lives of the most Eminent Foreign Statesmen	ib.
Maunder's Biographical Treasury	20
Roscoe's Lives of eminent British Lawyers	25
Russell's Correspondence of the Fourth Duke of Bedford	4
Shelley's Lives of the most eminent Literary Men of Italy, Spain, and Portugal	26
" Lives of the most eminent French Writers	ib.
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Lorimer's Letters to a Young Master Mariner	16
Manual for Mechanics' Institutions	18
Maunder's Treasury of Knowledge	20
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Tomlins's Law Dictionary	30
Waltzing, Reform your	31

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Conversations on Botany	7
Drummond's First Steps to Botany	8
Glendinning On the Culture of the Pine Apple	9
Grigor's Eastern Arboretum	10
Henslow's Botany	11
Hoare On Cultivation of the Grape Vine on Open Walls	ib.
Hooker's British Flora	12
" Icones Plantarum	ib.
" Compendium of English Flora	ib.
" Ditto in Latin	ib.
" and Taylor's Muscologia Britannica	12
Jackson's Pictorial Flora	13
Knapp's Gramina Britannica	15
Lindley's Theory of Horticulture	16
" Outline of the First Principles of Horticulture	ib.
" Guide to the Orchard and Kitchen Garden	ib.
" Introduction to Botany	15
" Natural System of Botany	ib.
" Flora Medica	16
" School Botany	ib.
" Synopsis of British Flora	ib.
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" " Lignosis Londinensis	ib,
" Encyclopædia of Trees and Shrubs	16
" " Gardening	ib.
" " Plants	17
" Suburban Garden and Villa Companion	ib.
" Cemeteries and Churchyards	ib.
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Rivers's Rose Amateur's Guide	25
Roberts On the Vine	ib.
Rogers's Vegetable Cultivator	26
Smith's Introduction to Botany	27
" English Flora	ib.

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Blair's Chronological Tables	4
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" Elementary do.	ib.
" Hist. of Roman Empire	ib.
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Laing's Kings of Norway	15
M'Culloch's Dictionary, Historical, Geographical, and Statistical	20
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Rome, History of	25
Russell's Correspondence of the Fourth Duke of Bedford	4
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Ladies' (the Young) Book	32

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